ORGANIC CHANGES AND FEELING.[1]

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The experimental work here reported was begun in the early part of November, 1903, and was continued until January, 1906, with omission of the summer vacations. The intention at the start was to test the organic reactions accompanying various mental processes, with special reference to Wundt's tridimensional theory of feelings, and this object has been kept in mind throughout. To this end the subjects were asked to give a careful account of the conscious factors involved, and to note particularly to what extent they might be called excitement or repose, strain or relaxation, agreeableness or disagreeableness. There certainly are such processes, whatever their character as feeling or sensation may be, whatever may be the physiological changes accompanying them, and these two points must be kept partly separate for the present. Some attempt will be made to determine more definitely with what kinds of processes we are dealing, but the success or failure of this attempt cannot destroy the value of the work on the organic reactions.

The possible expressive processes studied were the change in the volume of the hand; in the volume of the brain; in the heart rate; and to some extent depth and rate of breathing and the form and size of the plethysmographic pulse in brain and hand. The disagreement among the writers on the subject is so great that no estimate can be made of the present status of the problem except by a brief abstract of the recent literature, and to this I now turn.

It is needless to review the writings treated by Angell and Thompson in their article on "Organic Processes and Consciousness." It would be difficult to do it again so well. I can begin with a statement of the results obtained by these authors. They may be summarized as follows: when the attention process moves smoothly, respiration and circulation progress with regularity. Strained attention is accompanied by more vigorous bodily reactions than low-level relaxed attention,—but both agree in relative regularity. Breaks and shocks are followed by relatively violent bodily changes. Emo-

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tions are states of instability; attention is spasmodic and interrupted. This instability is greater in disagreeable than in agreeable states. Solving a problem that requires merely relatively strained attention is regular attention. If one becomes confused or anxious, we get irregular attention.

No factor, vasomotor, rate or amplitude of pulse, position or emphasis of dicrotic, or rate or amplitude of breathing changes regularly in one way for agreeable and the opposite way for disagreeable conditions. Almost all emotional states, agreeable or disagreeable, produced constriction. Amplitude of pulse decreases in almost all emotional states. The rate of the heart is sometimes increased on an average, sometimes decreased, sometimes not changed at all. Increase of rate is most frequent, but the more significant fact is the irregular rate with emotions.

The results with sensory stimuli vary. The most pleasant experience (harmony) always caused constriction. Unpleasant odors caused dilation in a few instances. The rate of the heart with sensory stimuli increases about as often as it decreases.

Mental application gave a slight amount of vasomotor change, frequently so slight fluctuations as to be hardly noticeable. Respiratory rhythm disappears. Intellectual states are distinguished from the affective states by the greater regularity, and not by any uniformity in the direction of change. In about half of the mental application tests there are both vaso-dilation and vaso-constriction in a single test. When the change is in only one direction, it is an even chance that it be dilation or constriction.

Lehmann, in the first part of his work, "Körperliche Äusserungen psychischer Zustände" gives considerable space to a study of the normal condition. Perhaps the most surprising statement is that the long undulations of the volume curve are called forth by vague conscious conditions which are not able to catch the attention. He says that these waves do not appear in deep sleep, and the changes in heart-rate are very small in the gradual undulations. Such a conception of these waves is a source of error throughout the book.

A concentration of the attention, according to Lehmann, is immediately accompanied by a few quickened pulses, during which the volume has a tendency to rise; then follow four to eight slow pulses and the volume falls; finally the volume rises again with quickened pulse. Taking all these phases together, the length of pulse is always shortened. If the activity is more lasting, the volume remains nearly at the normal after the last rise, but with much shortened pulse.

With involuntary attraction of the attention by a sudden external stimulus, the arm volume usually rises slightly at

first, then sinks, and lastly rises to normal. While the first pulses after the stimulus are shortened, the condition as a whole is characterized by a lengthened pulse, which shows more in the sinking than in the rising volume.

During strain of expectation, the volume of the arm is lessened, the height of pulse is small, the length of pulse varies but little from the normal. The reactions to various stimuli are obscured. If the strain is strong, external stimuli call forth only changes in the frequency of the pulse; if less, they cause a rise of volume which is soon lost. If the strain ceases, the volume rises with higher pulse.

In an indifferent mood, the bodily expressions of weak stimuli are independent of the feeling tone; if the attention to them is purely involuntary without active strain, the only change is lengthening of the pulse. If the stimulus causes some active attention, the volume changes of these states come in, but with lengthening of the pulse unless the active attention is too prominent. During a state of strain each new direction of attention is expressed by a volume change which is to be considered as a resultant of the changes which the new activity would cause of itself, and the rise of volume which is a consequence of the lessening of the strain. It is difficult to accept the author's explanation that, with maximal strain, the two forces arise side by side so that the volume remains nearly unchanged, while with weaker strain, one gets a predominating rise of volume.

Disagreeable sensations cause a strong and persistent fall of volume with decrease in the height of the pulse as well as its length. If the volume rises again, the height of the pulse rises also. With weak disagreeableness, the pulse begins to lengthen as the volume rises; with strong disagreeableness it shortens still more during the first of the rise and at the original level of volume the pulse length is usually markedly less than the norm.

A depressed mood is distinguished by the marked undulations. Agreeably toned sensations and other pleasant conditions, not very complex, express themselves by increase in the height and lengthening of the pulse; while the volume usually only immediately at the beginning shows a slight fall and then quickly rises above the original level. But one generally does not find all these changes in the same curve.

An external stimulus must affect consciousness in order to cause organic reactions. To the degree to which another state distracts attention from it, so far its special bodily expressions vanish. An agreeably or disagreeably toned sensation suggested in a hypnotic state calls out the same bodily changes which accompany the sensation when caused by a stimulus

under normal conditions, even though there may be acting a stimulus which of itself would cause different reactions if it came to consciousness.

In the second part of his book, Lehmann develops a theory of agreeableness-disagreeableness which he states briefly about as follows: when a psycho-physiological process demands no greater use of energy of a neuron than the assimilative changes are able to supply continuously, then the psychical effect will be an agreeable feeling while the physiological effect will be a stimulation of changes in other centres. The maximum of agreeableness is attained when the assimilative processes can just supply the demand. When these limits are exceeded, the agreeableness and the stimulation are both decreased; the demand in the active centres now causes an inflow of energy from the surrounding parts by which simultaneous processes in the latter are inhibited. We get then a neutral condition; and finally, if the need in the active neurons is so great that it cannot be supplied by the assimilation in connection with the intercellular stream of energy, the psychical effect will be a disagreeable feeling. An inhibition of other simultaneous processes will therefore accompany disagreeableness, except when this is of too short duration to allow an inflow to take place (as in fright).

Taking the curves published in Lehmann's atlas and the descriptions given by Lehmann of the conditions under which they were taken, Wundt attempts to show that in so far as the experience is exciting in character there is some increase in volume, increase in height of pulse, but no change in the pulse length; in so far as it is quieting, the reaction is the reverse. With agreeable states the volume is increased, the pulse heightened and lengthened; with disagreeable the reverse conditions hold. Strain gives a decreased volume, a weakened and lengthened pulse; relaxation the reverse. Wundt believes that in this way a better interpretation is obtained for Lehmann's results.

Brahn begins his article with a careful account of introspections in which he finds that Wundt's tridimensional division of feelings is justified. In his experimental work, he considers only the length and form of the pulse. He measures the single pulse beats, but very roughly, and uses only a few before and after the stimulus. He states that subliminal stimuli cause a slight lengthening of the pulse; that there are three pairs of changes in the pulse corresponding to three directions of feeling: agreeable states give longer and higher pulse, disagreeable shorter and lower; exciting higher and no change of length, depressing lower and of the same length; strain shorter and relaxation longer pulse. The changes in each case come in a

few pulses after the stimulus and last several beats. There is a periodic strengthening and weakening of the expression with strain corresponding to the variations of attention.

W. Gent finds with *Spannung*—a sort of indefinite expectation—if it is of short duration, a short fall of volume, more or less lessened height of pulse, and, most prominently, lengthening of the pulse; if of longer duration, the volume curve also remains low with very small waves.

With relaxation, the volume rises above the norm, generally with respiratory waves; the pulse is shortened. No feelings can be isolated except *Spannung* and *Lösung;* in all other places we have resultants.

Concentration of the attention as found in the solution of a problem or in counting marks gave a shallow and more regular breathing, a fall of volume and decreased height of pulse, with waves; there is no constant change of pulse length. From this he thinks the feeling is a mixture of "*Spannung*" and "*Erregung*." One must question, however, whether "*Spannung*," as he uses the term, is not the complex.

So far as a state was disagreeable it gave a fall of volume and height of pulse and shortened pulse length. These changes will be more or less complicated by the strain and exciting effects present, less so if the disagreeableness is strong. Agreeableness causes a rise of volume and height of pulse with greater respiratory waves; the pulse may be lengthened or shortened during the stimulus, but there is always a shortening after the stimulus.

Gent thought to get excitement by suggesting the arm as active or that its volume should rise; depression, by suggestion of the reverse. The reaction for excitement was the rise of volume, heightened and shortened pulse. The shortened pulse was obtained only by the method of suggestion. Depression gave the reverse reaction.

P. Zoneff and E. Meumann report quite fully the results of experiments in which they are mainly concerned with the accompaniments of mental processes in the heart rate and the breathing. They study not only the rate but also the depth of both chest and abdominal breathing. Working with attention to optical, auditory and tactual stimuli and to the solution of arithmetical problems, they find that, in general, a voluntary concentration of attention causes a slowing of the pulse and an inhibition of the breathing, greater in the chest than in the abdominal breathing. The breath is much more affected by the sensory than by the intellectual attention. The waves of the attention correspond to waves in the pulse and breathing changes; with weakening of the attention the pulse frequency and total amount of breathing increase.

Turning to the agreeable and disagreeable feelings, the authors state that all agreeable processes cause a shallower and more rapid breathing, with slowing of the pulse, all disagreeable processes give deepening and slowing of breathing and a quickening of the pulse. The chest breathing is more affected than the abdominal. If we consider both the rate and depth of thoracic and abdominal to get the total amount of breathing, we see that agreeable states lessen the breathing activity, disagreeable increase it.

The effects of the feelings vanish with a distraction of the attention by another stimulus. The authors also study the results of concentration of the attention upon the stimulus and upon the feeling, and show that a mere direction of the attention to the feeling strengthens it, but it is weakened if made the object of a psychological analysis.

One of the most interesting of the articles that have recently appeared is that by M. Kelchner, on the relation of breathing and pulse changes to stimuli and feeling. After a thorough criticism of Lehmann's work, the writer passes to the experiments on agreeable and disagreeable states caused by taste, visual and auditory stimuli. Agreeable tastes give quickened pulse, agreeable tones and colors a slowed pulse. The quickening of the pulse with taste stimuli is less, the more agreeable the experience, so that longer pulse seems to be here the natural expression of agreeableness. The pulse increases in rate generally with disagreeable states. The breath changes, with both agreeable and disagreeable, show great individual differences. Pulse and breathing are to a certain extent independent variables, and there is a great difference in the significance of the two as expressions of the feelings. The individual differences are found in depth and rate changes as well as in the relative part of the chest and abdominal factors, so that it is always necessary to consider both breath curves.

Strain was studied mainly by announcing a reaction of some sort which should take place at a second signal. Quickening of the pulse was the result; the breathing showed great individual differences. Relaxation gave the reverse of the expression of strain, and this was true, even in the individual differences. If strain precedes and turns to relaxation at an agreeable or a disagreeable process, the relaxation simply displaces the other feeling reaction, and the result is indifferent to the nature or degree of the agreeableness or disagreeableness.

Cutaneous pain gave rather uneven results. There was a tendency to faster breathing. The pulse was quickened, except with one subject.

A faster pulse and an irregular, generally somewhat quickened breathing, accompanied fright. There was a slowing of

the pulse afterwards, which seems to correspond to the feeling of relaxation which may follow fear.

A most careful recent investigation is that of H. C. Stevens in his article on the plethysmographic study of attention. He determines the volume changes and measures the heart rate from the plethysmographic curve,—a practice which will generally do very well, except that the method of counting the number of pulse beats in ten seconds, almost invariably used, is all too rough and meaningless.

Visual, auditory, and tactual attention, and attention to multiplication were studied. For visual attention, the rate of respiration was much increased, the pulse rate did not change consistently. With auditory attention the pulse rate was decreased, the respiratory change uneven. Both pulse and respiration were slowed for tactual stimuli. The results with multiplication were like those with the visual group, and the work was probably thought of visually. The most marked result in all attention was inhibited breathing and decreased volume of the arm.

Such variations of the results with the sense organ concerned leads the writer to the conclusion that the changes in rate of pulse and respiration are due simply to the process of sensation, not to the attention at all. And to be connected with this is the statement that "every sensory stimulus tends to produce a fall in the volume of the arm."

R. Müller has published an article in which he criticises the use of the plethysmograph for psychological purposes. The paper is well worth reading; but I do not think it necessary to review it nor to offer any reply, as I have recognized in an even more thoroughgoing way the facts that he urges.

In a recent book, Elemente der Psychodynamik, Lehmann gives a further discussion of the problem, and reports some experimental researches. After summarizing previous results and criticising the tridimensional theory, he develops his theory of feeling in connection with Verworn's theory of Biotonus. If assimilation ÷ dissimilation = 1. the psychic state is agreeable, and the stronger; the greater both assimilation and dissimilation are. If assimilation ÷ dissimilation < 1. the state is disagreeable. The Biotonus of the neurons will vary with the kind as well as the strength of the stimuli, and the value of dissimilation, with which assimilation ÷ dissimilation becomes less than 1. will vary with different conditions of the organism. If assimilation ÷ dissimilation < 1., the effect will be to inhibit other processes, and so the vagus centre. This will give an increased heart rate, which will send more blood to the brain, and so increase the assimilation. When assimilation ÷ dissimilation = 1., the vagus centre will be stimulated and so the heart

rate decreased, a result which is also teleological since the heart is relieved when great flow to the brain is not needed. "The feeling-tone is the psychical indicator of the Biotonus of the acting centre, whose bodily effects we find in the circulatory changes."

In the experimental work, Lehmann measures also the transmission time of the pulse waves, a method which is suggestive but which needs a more thorough treatment. He finds that no respiratory waves appear in the normal arm volume unless the breathing is very deep. They usually appear if the volume and height of pulse increase above normal; if they occur with quiet breathing and normal height of pulse, the subject is either sleepy or depressed. Of especial importance is the fact that he retracts his previous statement that the gradual undulations in the volume curve are due to vague conscious states. He now grants that there may be such waves without a correlate in consciousness, and which are, he thinks, due to a rhythm in the heart rate. He denies that these waves are effective in the time of transmission of the pulse wave, which means that they are compensated by vasomotor changes. But there are yet longer variations in the transmission time which are in the same direction in the carotid and radial arteries and in the opposite direction in the tibial, so that the two compensate each other and leave no trace in the volume. The results are to me, however, far from convincing.

"Every intense mental effort of considerable duration causes a greater frequency of the heart, expansion in the carotid, which probably continues after the work has ceased, and also constriction in the radial artery." This agrees with Berger's statement that concentration of the attention is connected with increased brain volume and height of pulse, which lasts until after the end of the work. Yet Lehmann finds that *Spannung* and expectation are expressed by decreased arm volume and small pulse which depend upon a constriction in the radial artery; and, in the carotid, no circulation changes can be indicated with certainty, which he connects with Berger's assertion that in *Spannung* there is no change in the brain curve, neither in volume nor height of pulse.

His results with sleep and related phenomena, seem to me very uncertain; I leave them for future consideration.

This writer finds that the characteristic of simple agreeable feelings is the expansion in the radial and the carotid; which agrees with Berger's result that agreeable processes go with a decrease in brain volume and increase in the height of the brain pulse.

To his former results with disagreeable states he adds that they are accompanied by a constriction in the brain. This he

infers from the decreased time of transmission of the pulse in the carotid, which continues after the heart becomes slower. Again he agrees with Berger's statement that "disagreeably toned sensations cause an increase in brain volume and decrease in height of pulsations in the brain." This contraction of brain vessels and decreased height of pulsations, it is explained, protects against a too rapid dissimilation.

The Peripheral Volume Changes.

The first experiments were designed to test the changes in peripheral volume and the depth of breathing. It was, at first, thought that the heart rate might be measured from the same curves, but this idea was soon abandoned for reasons to be discussed later. Three forms of the plethysmograph were used at one time or another during the experiments. We may consider them separately.

Zimmermann's modification of Lehmann's plethysmograph was used during the latter part of the first year's work. While this modification is probably inferior to Lehmann's original form, there are many objections to the use of either for this purpose. It is too much of a stimulus to the subject, involves too much preparation on his part and may easily become positively uncomfortable. It is little wonder that Lehmann obtained so many abnormal results, because the reactions were preceded by a state of *Spannung*. It is with great difficulty that movements are eliminated. Every swing of the arm in breathing, every jump, every contraction of the muscles of the arm is almost certain to be directly recorded in part at least. Again, it is too directly affected by the pulse in the large blood vessels, the outflow from the large veins, and, relatively, at least, cannot record delicately changes of volume so far as these are due to constriction or dilation of the small arteries. The results obtained by its use were not in conflict with those from the other instruments, but were not nearly so clear or certain. It was therefore abandoned in favor of the other forms.

It will be convenient here to notice a change made in recording the curve from Lehmann's plethysmograph. The Marey tambour is probably universally used for this purpose. But it is also very unsatisfactory. The unequal yielding of the rubber at the sides of the disk in response to the motion of the lever, the variable tension of the rubber at different heights of the curve tend inevitably to obscure the record. For this reason a piston recorder of large size with hard rubber plunger was made and used in place of the tambour. A much more delicate response, both as recording the long waves and any reaction to stimuli was obtained by this means.

The next plethysmograph to be considered is the Hallion-

Comte, an air plethysmograph. Objection may be made to this instrument in that it does not include all of any part of the body, so that some of the record desired may be lost; and that, if it is used on the hand, the subject may involuntarily squeeze the bulb, particularly at the time of a shock, and thus obscure the result. These abrupt movements, however, may in general be easily distinguished from other changes. The apparatus is useful when the pulse in the finger alone is not sufficient to give a fairly large record, as is often the case with women, and was retained for this purpose. It was also used for the peripheral pulse later when the brain and hand (or foot) curves were taken side by side. For it is the most convenient form available in taking a long record, as was done particularly in work on sleep. It was always used with a moderate sized piston-recorder with plaster of Paris plunger. When so combined, it is the most delicate apparatus we know for studying the vasomotor waves.

We come lastly to the finger plethysmograph, described by Lombard and Pillsbury in the *American Journal of Physiology*, Vol. III. This is altogether the most satisfactory when it can be used. It is easily and comfortably operated. It reports changes which are probably as nearly vasomotor as one can obtain. Movement of the arm affects it comparatively little. It was always used with the most delicate piston recorders, indeed the tambour will write practically no tracing with it. When so adjusted, the apparatus requires more care from the operator, particularly in attending to the recorder, but requires less from the subject, and is excellently adapted to the task in hand. Instead of warm water in the outer cylinder, a towel was generally spread over hand and plethysmograph if necessary. As a result, the air in the inner cylinder was sometimes growing slightly warmer during the first tests and causing a slow rise of the needle. But in almost no case was this large enough to interfere with an accurate reading of the result if a reasonably long curve was taken.

It must be confessed that there is one objection to this arrangement: the tracing is often very faint. The pressure of the needle of the recorder upon the drum must be so light that the mark is often not heavy enough. It can be seen easily if the records themselves are studied, but cannot be published except at considerable expense. For this reason, I shall select comparatively few curves for reproduction, and in fact mainly those illustrating agreeable and exciting conditions, the most disputed reactions. This, however, can be no great deficiency, since the whole story is practically told by these few, and since I have studied with special care any curves that might possibly be interpreted as the reverse of the correlation found.

Of the breathing record there is little to be said. A Sumner pneumograph was used on the chest and connected to a Marey tambour by rubber tubing. The intention was to show the changes in amplitude of chest breathing alone. This is, to be sure, inadequate to test a possible finer correlation between breath changes and mental process, since we should, for this purpose, know the total amount of breathing in both chest and abdomen; but it is sufficient to detect any changes that might materially influence the circulation. The variations in rate, like those of heart rate, were measured by more accurate methods in later experiments.

The kymograph used in the earlier experiments was one made by the Chicago Laboratory and Supply Co. That used mostly after the first six months was the Zimmermann pattern with Hering's slide. Along with the piston recorder writing the pulse and the Marey tambour tracing the breathing wave, and just above the latter, a magnetic indicator was used to mark the time at which stimuli were given. Above this was a time marker recording seconds in the first experiments, but this was of no importance after it was decided that the heart and breath rate must be studied in another way.

Among the stimuli used at one time or another during the experiments were agreeable and disagreeable smells, agreeable and disagreeable tastes, colored lights, deep and shrill whistles, chords or discords on tuning forks, music on stringed instruments (the violin and the zither), noises, attention to counting marks or a minimal sound, to a touch or to a multiplication, recalling of emotional experiences, listening to amusing reading, etc.

The arrangement in the first experiments was as follows: The finger plethysmograph was suspended at a convenient height from the floor by the side of a table. On this table were the kymograph, the rotating standard holding the recording apparatus, the syringe and its attachments used to adjust the level of the recorder needle, the electric key connected with the indicator, and part of the phials containing smell stimuli. On a stand near the operator, as he stood facing the kymograph, were the tuning forks and other objects needed to give the stimuli. The subject sat in a comfortable position next the plethysmograph; his arm rested in the swing and his eyes were closed except when he was told to open them to count marks, etc. The second finger was generally used in the plethysmograph. The room was quiet.

After the apparatus was adjusted so that all parts were working satisfactorily, a normal record was run for some time, a stimulus was then given, after which time was allowed for recovery, the kymograph was stopped, the stopcock turned and

the subject asked to give his introspection. This was written down and numbered to correspond with a number on the record. The indicator circuit was closed at approximately the time at which the stimulus was applied, although it was sometimes impossible for the operator to do this exactly.

In the later experiments the subject and operator were in different rooms. Both were dark rooms, that in which the subject sat was closed securely so that no light was visible except when an electric lamp was burning. The subject could hear practically nothing of the movements of the operator. The plethysmograph was suspended near the wall and beside a table. There was a hole leading through the wall to the other room. Through this hole passed the tubes from the plethysmograph and pneumograph to the recording apparatus which stood on a table next the wall. Through this also passed electric wires for signal keys, tubes attached to the whistles so that the operator could blow them at any time, and wires for two electric lights. What space was left through the hole was lightly packed with cloth. The electric lights were turned on or off from the operator's room. They were hung near the wall in front of the subject. Colored bulbs were made and used in them. The colors were red, yellow, green, blue, and violet, as well as the usual white. So the subject could be exposed to any of these lights or left in total darkness. A signal could also be easily given for any kind of mental work. The taking of the record and the introspections were analogous to the procedure in the first experiments.

The subjects for these experiments were Professor Pillsbury, Mr. Wright, a graduate student; Mr. Bayley, Miss Udell, and Miss Killen—senior students; and the writer. Professor Pillsbury, Mr. Wright, and Mr. Bayley served for most of the work. In about two hundred of the earliest experiments made, the introspections are insufficient to classify the experience accurately in the three directions of feeling. It was more or less a training period. The results obtained may be reviewed very briefly. And, in the first place, it may be noted that here, as in the later experiments, many tests gave no determinable result. Nor is this due to any fault of the apparatus, for undulations, and other changes when they occurred, were recorded more delicately than is usually the case. There was almost always some undulation, and the reaction was simply too weak to be distinguished from it. In truth this same fact was found with the Lehmann plethysmograph. Nor were the subjects in a state of strain; the pulse was normal, showing nothing of the constricted character it does during strain. And it might be an agreeable or a disagreeable experience which gave no response. A stimulus does not necessarily give

a definite reaction. All tests that could reasonably be interpreted as giving either rise or fall of volume were selected, the others neglected as determining nothing. Those also were omitted which were introspectively unsuccessful or meaningless; and of these there was a considerable number when the more accurate introspections were required.

As illustration of a test which gives no definite rise or fall of volume, we may give Chart W 31. (Pl. 1.) The stimulus was a chord, discord, and chord in succession. There was a marked change in the breath; the whole pulse curve is slowly rising with the warming of the air in the tubes, but shows no determinable reaction to the stimuli. The vasomotor wave here is not so large as is often found. Like phenomena may be obtained with simple or complex stimuli.

Summarizing roughly the results of these preliminary experiments, we find that nineteen agreeable stimuli gave a fall of volume distinctly, while four gave a possible rise. Fifteen disagreeable stimuli gave a distinct fall, and two a possible rise. Four shocks and five attentions to a touch sensation were accompanied by a fall. There was a fall with several cases of strain of expectation. One agreeable smell falls apparently upon a Traube-Hering wave, and in the same record is a disagreeable smell accompanying at least as prominent a wave. The same is true of two chords and a discord. Only one rise seems to be due to the stimulus, and this is with an agreeable smell which has led to deep breathing, the rise is apparently only a short effect of the breathing, and is followed by a fall.

Turning now to the records with which more careful introspections were taken, I shall describe a few typical cases.

W 166. Multiplying. The work was done easily, with some effort, but no confusion. Subject pictured the number and the result. He discovered a little mistake just at the end and that caused a momentary unpleasantness, but only a little and this near the end. Strain was practically the only feeling present. The volume curve as a whole was slowly rising, the effect of the stimulus was a fall with smaller pulse. Due to the displacement of the recorder needle in its arc, the whole pulse curve should be moved back somewhat; measurement shows the fall began about two pulse beats after the stimulus was given. The breathing was slightly deepened. The subject raised his finger a little to indicate where the work was done. (Pl. 1.)

W 167. The stimulus was again multiplying, and the conditions practically the same as in W 166, except that the work required a little more effort. The breath was not much changed, somewhat shallower. The volume decreased. (Pl. 1.)

B 20. The subject was asked to attend to a faint watch tick, to get, if possible, the attention wave. The condition was one of strain only. The pulse had just about recovered from a previous fall, the result of the work was fall of volume with lower pulse. Undulations were present in the pulse during the stimulus period, breath waves before the stimulus and in the latter part of it. The volume rose with the feeling of relaxation afterwards. The breathing was distinctly shallower during the stimulus. (Pl. 1.)

W 104. The stimulus was carbon-di-sulphide. Disagreeable, no particular strain of attention, nor excitement, nor depression. The result was a fall of volume, smaller pulse, and inhibited breathing. (Pl. 1.)

S 83. Oil of violet. An agreeable sensation with no particular strain of attention and no excitement. Subject in perhaps a little strain before. The mark was pressed a little early. The result is a fall of volume with smaller pulse. (Pl. 2.)

W 89. Camphor followed by cinnamon. Both agreeable, perhaps a little excitement, did not want either to cease. Again the result is a fall of volume. The breathing was a little deeper at first. (Pl. 2.)

B 9. (The curve is not reproduced.) Cinnamon. It was announced to the subject at (a) that cinnamon would be given. The smell was given at (b). The breathing was somewhat deeper after the announcement until the smell was removed. The pulse curve was slowly rising on account of the increasing temperature in the tubes. The stimulus caused a fall of volume and somewhat smaller pulse.

P 129. The stimulus was a violet light. It was agreeable and a sort of weird, little exciting light. There was marked depression when it was turned off. So the succession was an agreeable excitement, followed by a depression, the latter perhaps slightly disagreeable. The marker current was broken a little too quickly as the operator had to move a little to turn off the light after breaking the indicator circuit. There was a fall with smaller pulse beat both at the appearance and disappearance of the light. The breathing was scarcely changed. (Pl. 4.)

P 145. This record was taken with the Hallion-Comte plethysmograph. The stimulus was a violet light. It was agreeable and arousing, although the arousing effect was not so great as with the white light. The breathing was a little deepened. There was a preliminary rise followed by a fall. This was one of the very few rises obtained. And it may well be only a somewhat larger Traube-Hering wave, a kind of appearance which quite often occurs in an indifferent condidition *as well as in deep sleep*. (Pl. 2.)

B 27. The stimulus was the major triad C, E, G. There was no surprise, the stimulus having been announced just before. It was distinctly pleasant, possibly a little arousing. No especial strain of attention. The breathing was not changed uniformly. The volume curve had been artificially dropped a little before the stimulus, to bring the needle more nearly to a level position. The stimulus caused fall of volume with lower pulse. There was some breathing and Traube-Hering wave all through. (Pl. 3.)

W 87. (The record is not reproduced.) The stimulus was again the major triad, turned to a discord in the middle, then major triad again at the last. The discord was practically indifferent, the triad agreeable. Little surprise. The volume fell during the first sounding of the triad, while the feeling was little more than agreeable.

B 6 S. This is a curve taken while the subject was listening to music by Sousa's band. The feeling was agreeable and stimulating. This gives a decided fall in the volume, with smaller pulse. The Traube-Hering wave shows all through. (Pl. 3.)

W 76. The stimulus was the major triad. It gave a decided start, the tones were pleasant. With the tendency of the tones to be felt as pleasant and of the surprise to make the whole unpleasant, it is impossible to say that this was more than a state of excitement. Indeed this seems to be about the only way to get excitement unmarked by a particular agreeable or disagreeable tone,—to have both agreeableness and disagreeableness so suggested that one cannot say the feeling is to be called either. The result was a fall of volume with lower pulse. There was, of course, some attention, but no marked strain. (Pl. 2.)

W 96. Again C, E, G is the stimulus. A surprise, and not especially agreeable. Probably little more present than some excitement. The volume falls with smaller pulse. (Pl. 2.)

B 58. The violet light was on from the start and was turned off at the mark. This gave rise to a depressing, "closing in" feeling,—a somewhat disagreeable depression. The volume fell for a short time. The breath wave in the volume shows throughout. The subject was merely resting before. (Pl. 3.)

P III. The stimulus was an unexpected noise. The subject was startled. The experience was disagreeable and exciting, perhaps some strain later. The fall of volume was marked. (Pl. 3.)

B 28. Noise. Shock which lasted almost all through, a sense of disagreeable excitement and strain resulting. There is a temporary check in the breathing; a suggestion of rise in the volume curve just preceding the marked fall. In this case the rise may be no more than a broken breath wave, but we shall see later a meaning which such a rise might have. It is worth noting here, however, that there is often no suggestion of it in the shock tracings from the finger plethysmograph. The breath wave in the normal pulse is crushed out in the reaction. It should be stated that this subject almost always shows more or less breath wave in the pulse, although under no strain or abnormal mood. Different persons show great variations in this respect. (Pl. 4.)

It is useless to reproduce more of the results here, especially as almost every condition will be illustrated later in studying the changes in peripheral and cerebral circulation. I shall pass now to a treatment in tabular form.

Those cases were omitted which showed no determinable reaction, as well as those which could not, on the basis of the introspections, be classified. About one hundred and fifty were thus retained out of four hundred and fifty experiments made. To tabulate the results, columns were ruled upon blank paper for the following headings and in the order given: Number of the Experiment, Stimulus, Introspection of Conscious Condition, Volume Change, Wave in Volume, Height of Pulse, Depth of Breathing, Remarks. Each of the usable results was then carefully studied and recorded under each heading. The introspection was analyzed and stated in terms of agreeableness-disagreeableness, strain-relaxation, excitement-depression. In the volume column, C is used for fall, R for rise and Sr a secondary rise which quickly changes to a fall of volume. Under the heading "Wave in Volume," B is used for breath wave and T. H. for the Traube-Hering wave, or perhaps better called Mayer wave. + is "present" and "—" absent in the succession normal, reaction, recovery. When either period is not long enough to determine the character of the wave a "o" is entered in its position. ± signifies a stronger wave and ‡ a much stronger wave than is found in another period marked by a +. A —— in the wave column means that there is no wave that can be followed. In another column it signifies "no change." These abbreviations will also be used to tabulate the heart and breathing rate changes later.

I shall now give a few of the detailed analyses in the following table (Table I).

TABLE I.

No. of Exp.	Stimulus.	Introspection.	Volume Change.	Wave in Volume.	Height of Pulse.	Depth of Breathing.	Remarks.
U 40	Violet.	Agreeable.	C.	T. H. +++	Sl. decrease.	Increase.	
W 109	Cinnamon.	Agreeable.	Sr. then C.	T. H. +++	Decrease.	Inc. marked.	
W 112	C. E. G.	Agreeable.	C.	T. H. +−−	Decrease.	Decrease.	Little fall from the suspense at sudden stopping.
B 80	Discord (announced before).	Some surprise at announcement. Disagreeable.	C. at ann'ncement and at discord.	B. +−+	Decrease.	———	
B 10	Caproic acid (announced before).	Disagreeable.	C.	B. +−−	Decrease.	———	
W 128	Multiplying.	Strain.	C.	———	Decrease.	Irregular.	
B 22	Drawing on face (ann'ced before).	Strain.	C.	B. +−−	Decrease.	Decrease.	
S 107	Violet light.	Excitement. Agreeable.	C.	———	Decrease.	Increase.	
P 150	Blue light.	Agreeable. Exciting.	C.	———	Decrease.	Slight decrease.	
P 141	High whistle.	Excitement. Disagreeable.	C.	T. H. +−−	———	———	
W 79	Noise.	Disagreeable. Exciting. Strain?	C.	———	Decrease.	Increase.	Catch in breathing.
K 8	Drawing on face (ann'ced before).	Announcem'nt caused *Spannung*. Strain at drawing.	C. in each case.	T. H. ++−	Decrease in each case.	Decrease.	
P 128	Yellow light.	Pleasant. Depres'ng and disagreeable when turned off.	C. with light and also when turned off.	———	Decrease when turned on and when turned off.	Slight decrease.	
B 79	Sorrow by suggestion.	Disagreeable and depressing.	C. marked and quite irregular.	B. −+−	Decrease.	Increase.	Breathing slowed.

The expression 'Drawing on face' means that a figure was drawn which the subject should try to recognize. The stimulus in B 79 was by suggesting a very sorrowful event in the sub-

ject's experience. It will be noticed that P found a blue light more exciting than depressing.

We may now summarize the volume changes as follows, having regard to all the results retained as of value. Twenty-two cases of strain gave a fall of volume. Relaxation gave a rise. There may be a temporary fall at the first moment of relaxation. Eleven cases pronounced distinctly agreeable with no other feeling to be noted gave fall of volume, generally quite marked. Five agreeable gave a preliminary rise followed by a fall, in three of which the fall was much more marked than the rise. There was a rise with two others. Eighteen agreeably exciting caused a fall, and one a preliminary rise followed by a fall. (P 145.) Eight merely disagreeable gave a fall and one a rise. Five cases of excitement were accompanied by constriction. There was a fall with two depressing and four rather disagreeably depressing. Over fifty curves, mixtures of disagreeableness, excitement, and strain in nearly all proportions,—all gave a fall of volume, generally very large. Two indifferent stimuli caused a rise by comparative relaxation from a preceding strain.

It will be seen that the reaction is almost universally a decrease of the volume. It is probable that none of the rises were due directly to the stimulus. Six of those with agreeable conditions were with smells in which the amplitude of breathing is always more or less, generally greatly, increased. The first effect of deeper breathing is always a temporary rise. The other rise with agreeableness comes when the subject had been thinking intently upon another problem just before, and the stimulus, a chord, comes as a comparative relaxation. The rise with agreable excitement we have already seen is probably a Traube-Hering wave, and that with disagreeableness is about like it.

The importance of the Traube-Hering wave in confusing results is not generally appreciated. It is present in the charts published in the literature more than is usually recognized. There is probably no time when some considerable trace of it may not be obtained with fairly delicate apparatus. Far from being absent in deep sleep, it is more important then than in an indifferent waking state. It is often very prominent in sleep when the subject can remember of no dream even if waked immediately. I have easily traced it through several hours of deep sleep with practically continuous records, in fact through the whole night's rest. To be sure, it is often more prominent in the volume in a condition of drowsiness, particularly just before sleep, but not so marked after a long sleep. Even then it may not be so prominent in the other functions and sometimes the largest waves are found in sleep. It is

not due to vague conscious states, but is a physiological rhythm probably of the vasomotor centres and secondarily modified by a rhythm in the heart rate.

The size of the pulse in these curves always decreases with fall of volume and increases with rise of volume. This, of course, makes no test of the changes in the heart beat directly, —the vasomotor changes tend to obscure any variations in the force of the heart action itself.

On many of the records, the waves in the volume were not marked enough to determine their changes. The only correlations that could be worked out are as follows: With strain (close attention) there is a tendency to crush out the breath wave, and perhaps also to some extent with disagreeable smells. The Traube-Hering waves tend to become somewhat less with disagreeably exciting (five decreased, to twelve unchanged) and with agreeable and agreeably exciting stimuli.

A study of the results under the heading "Depth of breathing" showed some points of importance, all of them, however, more or less commonplace. Agreeable smells deepen the breathing and disagreeable and disagreeably exciting make it shallow. A disagreeably exciting sound or a noise tends to deepen breathing and often makes it irregular also. Agreeably exciting stimuli at least as often increase as decrease the depth. Attention to multiplying or similar work gives a decrease more often than an increase, but the decrease is comparatively small. By all means the most marked lessening is with attention to sensory stimuli, as in counting marks or listening to a liminal sound.

A phenomenon of some importance for a theory of agreeableness-disagreeableness is the effect of an abrupt stop. Subjects often stated that the sudden muffling of the tuning forks left them "in the air," lost for a moment. This is much more marked if an agreeable chord is stopped suddenly than if we are dealing with a disagreeable discord, although there is no thought in either case of "wanting to stop it." A sudden interruption of a simple agreeable experience seems to be more felt as a change, a shock, than a like interruption of a disagreeable, and in two or three cases a noticeable fall of volume accompanied this shock with the interrupted chord.

The only instances which gave a rise of volume that seemed to be due directly to the stimulus conditions were with attention to the member in the plethysmograph, the finger, to count the pulse and note any other sensations that may come from it. The condition is one of strain only. There is here, too, a tendency to constriction, but also apparently a tendency which may cause the volume with or without a temporary fall to rise with increased height of pulse considerably above the normal and remain there until attention changes. The breathing and

probably heart rate changes are the same as with tactual attention generally. The following instance may be given.

B 65. Attention to finger. No particular surprise, a little when asked to cease attending. Some difficulty was experienced to put attention on the finger. There is a preliminary fall followed by a more marked rise, with a return to normal afterward. The depth of breathing is somewhat decreased. (Pl. 4.) Four cases gave a rise without previous constriction.

The Volume of the Brain and of the Periphery.

The subject for these experiments was a young man, Carl Jahnke, a laborer of fully average intelligence. About two and one-half years before this work was begun he met with an accident which necessitated removal of a piece of the skull, roughly eight by six cms. in area on the right side of the head near the Rolandic region. Motor control in the left forearm was injured for a time. The wound had healed well and the patient had worked in Ann Arbor over two years without inconvenience. The hair is rather thinner on the scalp covering the opening, and there is a considerable dip or hollow at that place. The scalp forming the floor of this dip can be felt to pulsate.

The peripheral volume was taken from the hand in all the experiments on waking reactions to stimuli. A Hallion-Comte plethysmograph was used and connected to a piston recorder. The breath was recorded with pneumograph and Marey tambour as before. To get the change in volume of the brain, the capsule of a tambour was taken and the top covered with thin rubber. A piece of cork cut to fit the dip over the trephine was fastened to this rubber by means of beeswax. A strong cloth bandage was then tied firmly around the head, covering the forehead and the occipital protuberance. From this another broad bandage was passed over the trephine to the opposite side. The hair was parted away from the dip (shaving the head was entirely unnecessary), the capsule inverted and the rounded cork placed in the cavity. This done, the broad top bandage was pulled firmly but not too forcefully down upon the instrument and tied. The capsule was then connected by a flexible rubber tube to a delicate piston recorder. The kymograph employed in most of the work was the Zimmermann model mentioned above, and in a large part a long extension paper was used.

The subject was always in one dark room and the recording apparatus in the other as before. In the experiments here reported he was comfortably seated at a table next the wall. The stimuli given were like those used in studying the volume changes described above, and, in addition, a secondary current

was, in several tests, passed through the free hand of the subject. An exposed wire was, in these cases, employed for one electrode. This caused strong cutaneous pain with very little, generally no, contraction of the muscles of the hand and arm. Another person usually assisted me in giving many of the stimuli.

The introspections were taken as before. The subject was asked to describe his experience as fully as possible. He, of course, knew nothing of the tridimensional theory of feeling, but a little judicious questioning in addition to his description would bring out with practical certainty the character of the mental process. Naturally he was, at first, rather nervous, in a state of strain and uncertainty, and the results so far obscured. But it was not long until he became acquainted with the apparatus and methods so that the work became a matter of course. Hundreds of records have been taken from him during the past year almost as a part of his regular routine.

It may be noted here that the circulation in the scalp is negligible so far as its influence on the brain record is concerned. A chart will be given with a plethysmographic curve from the scalp and this will perhaps be sufficient to show the point. Movement also plays no important part in the tracings expressing the waking reactions to sensory stimuli. This is indicated by a consideration of the same curve. It was practically impossible to move the scalp in a way that would affect the trephine without interfering almost as markedly with the region of the bandages which always moved with the scalp. And any change in the bandages must have shown itself by raising or lowering the pressure in the tambour transmitting the pulse from the scalp at least as much as in the other tambour, since this one was over bone. And indeed it did in other experiments. But no such changes were noted in the curves showing the scalp pulse, although types of the only reactions in which movement could be suspected were obtained there. Furthermore, when movement is present its results are easily recognized. Several tests were made in which the scalp was moved in known ways by another person as also voluntarily (so far as he could) by the subject himself; and the effects are readily distinguished by their abrupt character and the kind of break they make in the pulse beats with which they start.

I pass now to a description of a few of the individual results. The chest breathing tracing is just below the indicator line; next is the plethysmographic curve from the hand; and below that the brain record.

No. 39. The subject was asked to attend to a faint watch tick. In a normal condition before. Considerable effort was required. Relaxed afterward. The volume of the hand fell with decreased and

rounded pulse. There was a secondary fall at the first period of relaxation after which the curve returned to the normal. The brain volume rose gradually with higher pulse, then returned regularly to normal; the dicrotic was relatively more elevated in its position on the pulse beat, and a little sharper. The breathing was rather shallower. (Pl. 5.)

No. 42. Assistant drew a figure on the hand of the subject, who, with eyes closed, was to attend to and determine the figure if possible. No surprise. Could not tell what figure was drawn. The condition was primarily strain of attention. The amplitude of breathing was somewhat decreased. The volume of the hand fell with more rounded pulse. The brain changed about as in No. 39. (Pl. 6.)

In this and all other charts the mark "art" signifies that the change was made artificially by means of the piston used to regulate the height of the needle of the piston recorder.

No. 40. (The curve is not reproduced.) A series of figures to be added, divided, etc., was read to the subject, who was asked to perform the task suggested. He, with closed eyes, followed the problem without confusion, except a little at the last. The amplitude of breathing is increased. The volume of the hand was decreased as usual. The brain volume rose a little quickly, then fell back and increased gradually to its greatest volume near the end. It then began its return to normal. The dicrotic in the brain pulse was higher in its position on the beat.

No. 88. Only the end of this experiment is given. The subject had been attending to a faint sound for some time, and ceased attending at the upward movement of the marker. There was no surprise when the signal to stop was given, but there was a marked feeling of relief. During the first period of relaxation there was a fall of the hand and rise of the brain volume, after which each returned to normal. There was but little change in the breathing. (Pl. 7.)

Such alterations in the brain volume are often as great, sometimes greater than in this curve.

No. 69. At a signal from the operator, the subject took chocolate into the mouth. The signal had been prearranged, so that there was some expectation of its coming, still there was a little surprise. The taste was agreeable. In the movement of opening the mouth, etc., the bandages were apparently disturbed somewhat, giving a rise in the brain curve which seems to be at first a combination of movement and vasomotor change. The volume and size of the pulse of the brain were increased with more marked undulations then gradually decreased. The volume of the hand fell. The breath was little disturbed except by taking the chocolate and occasional movements of swallowing. (Pl. 8.)

No. 144. Chocolate was again the stimulus. The subject was normal before and took the chocolate with less movement of the mouth. The taste was very agreeable. The volume of the brain increased with greater pulse and the dicrotic a little nearer the apex. The hand decreased with smaller pulse. The breathing was little changed except by swallowing at times. (Pl. 9.)

No. 73. The stimulus was quinine. The subject expected the signal, and there was but little movement in taking the substance into the mouth. The taste was very disagreeable. The volume of the hand fell markedly with low pulse; that of the brain rose with higher pulse and gradually returned to normal. The dicrotic in the brain became higher in position and less prominent. The breathing was a little uneven. (Pl. 10.)

No. 61. The stimulus was violet light. It was markedly pleasant

and stimulating. The volume of brain and hand, were nearly, although perhaps not quite, recovered from the effects of the preceding test; that of the hand fell with the light, that of the brain rose, and both then gradually returned to normal. The dicrotic in the brain was sharp throughout. The breathing curve was interfered with by the fact that the needle of the tambour was striking against the electric marker at the top. The breathing was somewhat deepened at first by the light. (Pl. 11.)

No. 55. The stimulus was a chord. It suggested some church music to the subject. It was agreeable and somewhat arousing. The volume of the hand fell with decreased pulse, that of the brain rose with increased pulse as usual. The amplitude of breathing was decreased at first. (Pl. 12.)

No. 60. The white light was turned out at the marks. This caused the subject to feel depressed for a time. Again there was fall in volume of the hand and slight rise in that of the brain. (Pl. 11.)

No. 78. The stimulus in this experiment was an unexpected deep whistle which greatly frightened the subject. There was a temporary rise in the volume of the hand, but with decreased pulse. This was followed by a marked fall. The brain volume rose greatly with increased pulse, then fell nearly to the normal temporarily, finally rose again and gradually returned toward the normal later. The dicrotic was less prominent but no higher in position. This behavior is quite characteristic of all intense stimuli; and it may be noted that there is often some trace of it in part of the curves given above. (Pl. 13.)

No. 92. A chair loaded with weights was tipped over behind the subject seated in the dark room. Subject reported that he was "scared to death." Could not make out what was the trouble. It was a considerable time before he could collect himself again. The breathing was checked at first, shallowed and showed a tendency to inspiration, after which it became deeper. The volume of the hand rose a little with decreased pulse, then quickly fell so markedly that the needle had to be raised artificially several times. The brain volume rose with increased amplitude of pulse beat, then fell with an undulation to normal. It will be noted that the pulse beat at the time of this fall was smaller and more rounded. With the later fall in this same record it is the nearest approach to a tricuspid pulse that I have found in the brain, except in one curve to be given later. The slightly greater pressure of the needle upon the drum may be responsible for this, but it certainly suggests a hampered pulse. After this temporary fall, the brain volume rose so greatly that the needle of the piston recorder stuck at its base and could rise no higher, so that the full form of the pulse is not shown. The amplitude of the beat was enormous. Finally there was a quick fall with somewhat rounded pulse, and the needle had to be raised artificially. (Pl. 14.)

It is to be regretted that the record was somewhat marred in removing the long paper. There was apparently a slight leak in some of the tubes connected with the brain recorder.

No. 143. A whistle was blown loudly near the subject in the dark room. It caused a marked shock and jump, fright, which persisted for a considerable time. There was irregularity due to movement in the breathing curve, with a decided tendency to deeper inspiration, and fall of its level. The hand volume was so obscured at first by the movement that one cannot determine with certainty the changes which took place, but there was probably a preliminary rise with small pulse followed by a marked fall. The brain increased in volume greatly with high pulse, then fell with lower and somewhat restricted pulse, and, after a smaller undulation, rose again with enormous pulse, and finally returned gradually towards normal, with dicrotic nearer the apex than in the normal. (Pl. 15.)

No. 98. The stimulus was a secondary circuit through the free hand of the subject; an exposed wire was used as one electrode. It did not pain much at first, but became very strong later. It was then very disagreeable, but did not cause contraction of the muscles of the hand and arm. The breathing became irregular, with no distinct check in it, the level of its curve fell. The hand volume increased at first with smaller pulse, then decreased markedly. The brain showed a temporary rise of volume corresponding to the rise in the hand, followed by a fall, after which the second rise appeared. The hand then constricted again more markedly, probably as the current became stronger. The brain increased greatly, decreased and increased again just after the stimulus ceased. The subject expected another shock afterward. The volume gradually returned to normal. (Pl. 16.)

No. 141. The stimulus was again an electric current. It was strong and painful throughout, although not without some variations in the intensity. It did not cause contraction of the muscles. The breathing was deeper. The volume of the hand fell from the start with restricted pulse, and was raised several times artificially. The volume of the brain rose with two waves, a further short rise occurred near the end of the stimulus, after which it slowly returned to normal. The dicrotic moved nearer the top of the brain pulse wave during the stimulus. (Pl. 17.)

A check in the revolution of the drum caused a deformed curve a short distance before the end of the stimulus.

No. 157. Several experiments were made to test the part which the circulation in the scalp might play, as well as to determine further the effects of any possible movement, and this record has been selected to represent the reactions. A second pneumograph was used upon the abdomen. This recorded by means of a Marey tambour the curve above the electric marker line. The plethysmographic curve from the scalp was recorded in place of the volume of the hand. A second instrument, like that used over the trephine to transmit the changes of the brain to the recorder except that the cork used was flatter, was placed in an analogous position under the same bandage on the other side of the head. It was connected to the piston recorder before employed to write the hand changes. The circulatory variations in an area of scalp similar to that affecting the brain curve were thus recorded. Any movement of the bandage, which practically moved with the scalp, must affect this second instrument even more than that over the trephine, since the bone under the scalp would cause every change of position to be fully transmitted to the recorder.

The stimulus for this record was a low, grating noise made at the door of the dark room in which the subject was seated (the mark is a little late). It caused marked fright which did not entirely cease until the drum stopped. There was very little check in either the abdominal or the chest breathing. The volume of both brain and scalp increased with higher pulse, then decreased with smaller pulse, and lastly repeated this process a second time. The changes in the two curves go together. The pulse was almost anacrotic throughout. (Pl. 18.)

About one hundred and fifty curves showed clear results. In general, all agreeable or disagreeable stimuli, all sensory attention or attention to arithmetical problems, all agreeably exciting light or music gave a fall of volume of the hand with smaller pulse and more rounded dicrotic, and rise of volume of the brain with larger pulse, often a dicrotic raised in position and made sharper. A sorrowful condition as well as the de-

pression from sudden darkness produced the same result. The strain of expectation when a neutrally toned stimulus was announced before it was given acted like any other attention—it increased the volume of the brain and size of the brain pulse, and decreased the hand volume and size of pulse. With relaxation there was quite often a fall of the hand volume and rise of that of the brain during the first period, a testimony to the importance of the adjustment period generally; after that a gradual increase of the hand and decrease of the brain to normal.

The first point to be noticed in studying these volume changes is the double character of the reaction, particularly with strong stimuli, fear, etc. The volume of the hand increases first with smaller pulse and then falls quickly to a much lower level with rounded pulse; that of the brain increases with large pulse at first, then decreases nearer or quite to normal and sometimes shows almost an anacrotic pulse, then finally rises markedly with high pulse and gradually returns to normal. There may be even further secondary undulations.

If you ask as to the cause of these changes, several possible reasons suggest themselves. In the first place, it may be thought that the sudden contraction of the muscles of the abdomen, as when one braces one's self for an effort, would force the blood from the visceral organs into the brain and peripheral parts, and that with the release of this tension one gets the secondary fall of the brain. But a voluntary attempt to expire, when the nose was held closed, gave no such quick, large rise as we find here. Again the breathing change is not nearly long enough to account for the rise which may cover several breaths; and in addition the main tendency is to inspiration modified by the irregularities of movement. This type of reaction also occurs in greater or less degree when there is no appreciable check in the breathing, as in some cases of fright and almost always with the painful electric shock. And in the latter case there was also no considerable contraction of muscles which might influence the reaction by compressing the veins.

The only other probable explanation of the preliminary rise is to ascribe it to a sudden violent contraction of the splanchnic vessels. For the change occurs in the brain, hand and scalp at the same time. The smaller size of the pulse in the hand may be due to the marked tendency of the arteries there to constrict also. Even then there are at least two possible explanations of the secondary fall in the brain. It is quite probable that the spastic constriction of the splanchnic is followed by as sudden dilation, or there may be more than one such wave. The sec-

ond more lasting rise of brain volume follows from the general constriction and consequent rise of pressure. This explanation is indicated by the fact that the later as well as the earlier changes of the brain and scalp occur together. It is possible, too, that there is a local contraction of the brain vessels themselves which is afterward overpowered by the rise with the general reaction. Such a possibility is suggested by the more nearly tricuspid form of pulse often occurring during this period and later. It may very well be that such local vasomotor control is active, although it is to be expected that it would not be sufficient alone to account for the decrease of volume. To decide the question, if possible, I expect to test other aspects of this reaction soon, especially as it appears in blood pressure measurements and in the rate of transmission of the pulse wave.

Another factor that may play some part in these volume changes is the variation of heart rate with strong stimuli which we shall study later. The waves in the rate, however, are of shorter duration and relatively little marked. Even the secondary decrease in rate below normal cannot explain the fall to normal or lower in brain volume, if we suppose it is working against a constriction of the arteries. For it does not occur in a majority of cases, and is generally small when it does appear, while there is practically always a decided volume reaction of this character.

A careful examination of almost any one of the curves will show that the Traube-Hering wave in the volume is quite parallel in brain and hand. A crest in the one corresponds to a crest in the other. The question at once arises whether this wave is here an active phenomenon so far as the brain and periphery are concerned, or whether the changes in each follow passively from the reverse changes in the splanchnic, as was found by Roy and Sherrington to be the case with asphyxiated animals. Here again an attempt will be made to measure the blood pressure changes; the variations in pulse form are doubtful. But I cannot discuss the matter here.

It should be noted also that the waking reactions in the brain volume are different for different positions of the body, particularly when the subject is lying down. These differences and their causes are not important in this connection. I must leave them together with a more detailed study of the Traube-Hering wave, sleep and other more physiological matters for further treatment. In truth, what I have said here of vasomotor control in the brain is practically an extract from a more extended article on the brain circulation to appear in the future.

The Rate of the Heart and Breathing.

In the first experiments designed to test the changes in heart rate, use was made of a Sommer sphygmograph on the left wrist. This was connected with a piston recorder writing on the kymograph. A parellel record was taken from a finger of the same hand, using the finger plethysmograph with a piston recorder. But, since it was found that there was no appreciable difference between the heart rate as measured from the plethysmograph curve and as measured from the sphygmograph, the latter was omitted in the later experiments and either a finger or a Hallion-Comte plethysmograph tracing measured for the rate. A pneumograph was applied as usual in the later experiments; no breathing record was taken in the earlier.

A long extension paper was used with the Zimmermann kymograph mentioned above. In a vertical line with the piston recorder needles and the electric marker used to indicate the stimulus, another electric marker wrote the time in one-fiftieths of a second. It was run by a current interrupted by a tuning fork. The drum revolved quite fast, so that the record of the time marker could be easily read. The subject was seated in one dark room, the recording apparatus placed in the other as before.

The subjects were Professor Pillsbury, Mr. Bayley, Mr. Jackson, Mr. Schottstaedt, and Mr. Wright. Mr. Jackson was an advanced student in psychology. Mr. Schottstaedt was just beginning his work in the department.

To study the results, the points at which the upward stroke of the pulse beats began were carefully marked, and lines drawn through these points perpendicularly to the time line. When necessary, correction was made for the displacement due to the movement of the recorder needle in an arc; but this error was usually found so small as to be negligible. The length of each pulse was then counted in one-hundredths of a second, since it was possible without difficulty to estimate as near as one-half the distance between the one-fiftieth of a second marks. The errors are believed to be very small, almost never more than one unit, and such an error is of no importance in the face of the changes which the heart rate shows.

These results were then plotted upon co-ordinate paper with a heavy reference line ruled horizontally through the middle and lighter parallel lines drawn approximately six mm. apart on each side of this. There were similar lighter lines vertically across the paper. The standard line was given the value of either thirty-five, forty, forty-five or fifty one-fif-

tieths of a second (represented as P 35, P 40, P 45, or P 50 at the left end of the line) and each unit of distance along a line vertical to it means one one-fiftieth of a second. Above is positive, below negative to the standard. Units of distance along it represent pulse beats. Points were placed in the appropriate positions on the vertical lines to mark the length of each pulse in one-hundredths of a second, and a smooth curve drawn through these points. A rise in the curve, therefore, means an increase in the length of pulse, or a slower heart rate; a fall in the curve means a shorter pulse, or a faster heart rate. The points at which stimuli were given or removed were marked with crosses. At times, a few pulses were so obscured that they could not be counted individually with accuracy, although the record as a whole was good. These were sometimes omitted and the number omitted marked in the blank space on the record; more often they were averaged,— the total time divided by the number obscured. The fluctuations in a portion thus averaged are, of course, lost, but the distance is always small. Such parts of the curve were drawn in a dotted instead of a smooth line.

The breathing record was treated similarly. The lines were drawn through points marking the completion of the inspiration, which could be determined fairly easily. The single breaths were then counted in one-fiftieths of a second and the results divided by 2, 3, or 4 as necessary, that they could be recorded on the chart with corresponding pulse record; the plotted lengths must, therefore, be multiplied by this number to give the true length. The point representing a breath was placed on the pulse line, in which the inspiration was completed. A dotted curve was drawn through these points. The value of the standard line for the breath record is represented along with that for the pulse record at the left end of the line.

All results which were introspectively bad, or which for any other reason were unsuccessful, were rejected and not counted and charted.

The charts are themselves sufficient justification of this method of studying the changes in rate, and show the comparative uselessness of any rougher method, such as counting the number of pulse beats in ten seconds. In the first place, there are often shorter temporary reactions whose character can be seen only by such a method. Again, even the general changes are uncertain if studied less accurately. There are large variations from purely physiological causes, as Lombard and Pillsbury have already shown; and the kind of results one seems to get by any method of averages depends far too much upon where in one of these waves one begins his count. If

the reaction is not large, almost anything can be proved, or seem to be, by starting at the appropriate point. The true character of the process is seen only in charts of this kind.

I turn now to a detailed study of a few typical charts.

B 24 R. Pl. 19. No stimulus was used, the subject reported the record normal and indifferent throughout. It is given to show the character of the changes which may take place from physiological causes and are not to be ascribed to any accompanying mental process. The Traube-Hering wave and the breath rhythm both show distinctly, and there is at first a small rise, later, a small gradual fall of the general curve. Several normal, indifferent records were taken, all showing similar characters. Of course, one may have a gradual rise or fall at any part instead of the one at the end, the other at the beginning as here. In the light of this, much care is necessary to be certain of any conclusion one would draw as to the reaction with a mental process.

P 32 R. Pl. 19. This shows the effect of a voluntary muscular movement. The subject moved his free hand to his face and held it there a few seconds, then returned to the former position. There was no particular feeling to be noted, only the consciousness of an indifferent movement. The result was a short increase in rate followed by a greater but temporary decrease. The curve then returned to normal and is but little affected by moving the hand down to the table again. There was a fall in the volume record at the time of raising the hand.

P 10 R. Pl. 20. Multiplying. The subject pressed a signal key when the problem was solved. Work done without confusion, required some effort. A condition of strain. Some feeling of relaxation afterward. The pulse rate was increased and recovered before the end. There was apparently a slight increase in the first moment of relaxation.

P 18 R. Pl. 19. Multiplying. It required a good deal of effort all through and the subject got the result just at the end of the record. Feeling of strain. It is to be regretted that several pulses at the beginning of the record could not be counted accurately enough to plot, but it could be determined that all were above 40. The pulse rate was therefore increased considerably, more at the last.

J 2 R. Pl. 21. The subject was asked to attend to a faint telephone snarl to get the attention waves. There was no surprise at signals. The feeling of strain was marked, and there was some relaxation at the end. No other feelings were present. The rate was decreased on the whole. The first large waves were in all probability Traube-Hering waves in the rate, which were partially stopped as the rate was slowed. There was a small increase in rate after attention ceased. The breathing was markedly shallower.

B 4 R. Pl. 20. The subject was asked to count the closely written marks of a time record. Normal before. Considerable effort of attention. Strain was the only feeling, some relaxation afterward. The pulse was slower. There was an increase in rate after attention ceased, and apparently a large wave was coming in as the record stopped.

J 8 R. Pl. 21. The conditions were similar to those of B 4 R. The feeling was strain followed by relaxation. There was a marked temporary increase in the heart rate followed by a more lasting decrease and a gradual increase afterward. The breath wave in the pulse was less marked during the attention. The breathing became more rapid and shallower.

P. 28 R. Pl. 22. A telephone snarl was decreased in intensity until one could hear it at times but not continuously. When the subject was again in a normal, indifferent condition, the kymograph was started,

and, at a signal from the operator, he attended closely to the sound, pressing a signal key with a finger of his free hand while the sound was audible, releasing the key when nothing could be heard. As soon as the paper had run around once, the kymograph was stopped and the paper dropped so that another curve could be taken. The subject attended continuously. After a few minutes the drum was again started, and when it was about one-half way around, the subject was signalled to cease attending. The paper was allowed to complete its second revolution. A record was thus obtained of the heart rate at the beginning and end of a long continuous effort of attention. The two periods are marked "1st run" and "2d run." The subject reported that it required a concentrated attention, feeling of strain. There was a feeling of "letting down" relaxation afterward. The pulse length was not changed at first, but increased in the latter part of the first run and still more during the second run. There was a temporary increase of rate at relaxation. The Traube-Hering wave in the rate, present in the normal, was almost crushed out with the increase in heart rate during the attention, and apparently was coming in again as the second record ended.

J 20 R. Pl. 22. The arrangement was similar to that in P 28 R, except that the problem was to differentiate two weak sounds. The subject reported that he was indifferent before the stimulus, there was no surprise at the signals, attention was close, with feeling of strain only, and there was distinct relaxation when signalled to cease attending. The pulse rate was very little changed during the first run, perhaps a little decreased. It was faster in the second run, and became slower during relaxation with one large wave just after the stimulus ceased. The Traube-Hering wave was present throughout, but was most marked in the normal and first few seconds of attention, less prominent later. The breath wave in the pulse was smaller during the stimulus. The rate of breathing was somewhat increased, and the amplitude distinctly decreased, particularly at first. It will be noted that there was a wave in the breath rate which suggests in its period the Traube-Hering wave found in the volume. I shall call this the Traube-Hering wave in the breath henceforth, without here discussing its nature. This wave is large in the normal part of the record under review, but is more or less broken up during the stimulus period.

J 7 R. Pl. 22. This again was a long continuous concentration of attention but this time visual,—the effort was to count the closely written marks of a time record. The subject moved the fingers only a very little to mark the number of marks instead of pressing a signal key. In other respects the experiment was conducted as in the long anditory attention tests. The subject was normal before, and reported no surprise at signals, constant attention with feeling of strain, and relaxation after the signal for the counting to cease. The heart rate was not definitely changed during the first run, but had increased in the second run. There was a temporary increase in rate at the first period of relaxation. The Traube-Hering wave in the heart rate was distinct in the normal and stimulus periods, uncertain during relaxation; the breath wave more prominent in relaxation than elsewhere. The breath rate was greatly increased in the stimulus period, less in the second run. One longer and deeper breath will be noted just before the end of the first run; a larger breath wave in the pulse rate accompanied it. The amplitude of breathing was greatly diminished during attention. Traube-Hering in rate of breathing was largely obscured.

B 17 R. Pl. 23. The subject took chocolate into the mouth with very

little movement or disturbance. The taste was very agreeable. There was no strain, excitement or other feeling to mention, simply the agreeable taste. The pulse rate was greatly increased. The Traube-Hering wave present in the normal was less in the first part and disappeared in the last part of the stimulus.

P 48 R. Pl. 23. Chocolate. The subject had held the candy between his teeth in a slightly strained position before; otherwise normal. The taste was agreeable, there was a little relaxation from the slight strain, no excitement. The rate of the heart was increased on the whole and the Traube-Hering wave became more prominent than in the normal. The breathing was very little changed, there was less wave in it in the later period.

J 10 R. Pl. 23. Chocolate. Agreeable. There was no disturbance nor other feeling than agreeableness. The pulse rate was increased and more of an undulation came into the curve. The breathing became faster on the whole, but with enormous waves.

P 49 R. Pl. 24. Quinine was taken into the mouth with very little movement. It was very disagreeable; possibly a little excitement; but that very slight. No other feeling. The pulse rate became much faster. The large Traube-Hering waves present in the normal were almost crushed out during the reaction.

J 3 R. Pl. 24. The stimulus was quinine. There was a little surprise when the signal was given to take the quinine into the mouth. The subject reported that the taste was very disagreeable, and that was all there was to the feeling. The pulse became faster and the Traube-Hering wave in it less marked. The breathing also was quickened, the exact character of the undulation in its curve is uncertain.

J 15 R. Pl. 25. The stimulus was lively music played upon a zither. It began at the cross and lasted the remainder of the record. The first strain was not particularly agreeable because too loud, but later the music was exhilarating (exciting) and agreeable. The pulse rate was increased and the Traube-Hering wave in it gradually eliminated. The breathing became faster, the wave in its curve was of uncertain character. The amplitude of breathing was somewhat less during the stimulus.

P 41 R. Pl. 26. Music, very pleasant and exhilarating (exciting). The pulse rate became faster and the prominent wave in it somewhat less. The breathing was also more rapid during the stimulus. There was a large wave in the breath rate, the relations of which are not very evident.

P 43 R. Pl. 26. The stimulus was again music of an agreeable exciting character. There was possibly a little strain. The pulse was shortened, particularly in the latter part where the agreeable excitement was greatest. The first part of the curve shows what changes may take place without accompanying mental processes that will explain them. The Traube-Hering wave in the heart rate became less prominent during the reaction. The breathing was on the whole somewhat faster with the music.

P 45 R. Pl. 26. Music was again the stimulus, this time pleasant and markedly depressing. The pulse rate was increased, as was also the rate of breathing. The undulation is not very noticeable in either.

J 16 R. Pl. 27. The stimulus was pleasant and depressing music. The pulse rate was faster, the wave in it less marked during the stimulus. The breathing was also more rapid with the music; the Traube-Hering wave in the breath rate is fairly well shown, somewhat less in the reaction.

S 9 R. Pl. 25. A yellow light was turned on at the first mark, off at the second. The subject reported that it was agreeable to a certain extent

in contrast with the darkness, but that the color was not agreeable. Its disappearance was hardly noticed. The pulse was slowed and the breath wave in it more prominent. Very few records were taken with this subject. Two like results were obtained from him by use of a pleasant exciting violet light, and one with the depression from turning off a light. No determinable change occurred with a long effort of attention. An increase in rate accompanied one multiplication test. Two strong shocks with an unexpected whistle and one very irritating light gave faster rate. The subject was unaccustomed to this work and almost always reported that he was "expecting the stimulus." Most of the reactions were probably a release from strain, and have little meaning as accompaniments of the mental process coming into an indifferent state. It was perhaps a mistake that few lights were used as stimuli with the other subjects and only three cases were counted. But they were omitted because they had no effect to speak of, only a suggestion of an increased rate in two of the three cases.

P 38 R. Pl. 27. A loud, unexpected whistle was blown. The subject was startled and jumped. It was disagreeable, exciting strain. Recovered very soon. The pulse rate was temporarily increased, then temporarily decreased, after which it returned to normal. There is a large Traube-Hering wave in the latter part of the normal period, and possibly throughout the remainder of the record. The breathing was made more rapid for a short time.

J 21 R. Pl. 28. The stimulus was again an unexpected whistle. It frightened the subject. Excitement, disagreeableness (and strain?). The general result was a faster pulse for a time, the breath wave in it being a little less marked in the reaction. The breathing became faster for about the same period that the heart rate was increased.

B 10 R. Pl. 28. A particularly sorrowful event in the experience of the subject and to which his attention turned easily was suggested. He reported that he was normal before, that a few seconds after the suggestion was made he fell into a distinctly sad mood, and when told to return to his former indifferent attention he could feel his body drooped, one might say relaxed. It was, apparently, a condition of disagreeable depression for the most part, with perhaps a very little strain at the start, although the subject did not give an accurate account of the feeling directions involved. The pulse rate was slightly decreased, but the difference was not enough to have any meaning. The more important point is the marked Traube-Hering wave which came into the curve.

About one hundred and ten records were counted, charted, and then tabulated by the same methods used in the work on volume changes. Such a study of results showed that the strain of expectation tended to increase the pulse rate. Movement in two tests increased, then decreased it. Multiplying, which was accompanied by a feeling of strain only, gave a marked increase in three cases, no decided change in three. With short close auditory attention there was a decrease in two tests; in a third, no change at first, increase in the latter part. Similar visual attention had as its accompaniment a decrease in rate, twice, a temporary increase followed by a decrease, twice. At least one of these increases was probably caused by movement of the subject as he began attending. Long, continuous visual attention gave in three cases a decrease in rate at first,

followed by an increase later; in two no change at first, increase in the second part; in one there was no change except a slight increase from a movement at the beginning. Long auditory attention caused no change, once (with subject S, mentioned before); a short increase followed by a decrease in the first part and increase in the second part, once; slower rate at first, faster later, in two instances; and three times, no change at the beginning, quicker beat in the latter part of the first run and in the second run. Of eight results with chocolate, in seven of which agreeableness was pronounced the only feeling to mention, seven gave increased rate, generally very marked; one gave a short decrease followed by a more prominent increase. There were five records of a disagreeable taste, in two of which there was also a little excitement,—all showed more or less marked fall in the curve. There were seven trials of music which according to the subject's introspection were agreeable and exciting. All resulted in a faster rate, generally the increase was very marked. The emotion of joy, which was almost entirely agreeable excitement, was accompanied by a quickened heart in one case, no change in two. Omitting one instance which was obscured by the effects of movement (the subject was not prepared) there are left four cases of agreeably depressing music, in all of which the pulse was shortened. If we except the results with S which were uncertain, the rather disagreeable depression from suddenly turning out a light caused an increase in rate in four tests, no change in one. Four records were taken with the emotion of sorrow, none of which showed a determined change of rate. The same was true of two with the emotion of anger. Eighteen records were retained, in which the stimulus was a loud unexpected whistle. The stimulus induced a shock, disagreeable excitement with more or less strain. Two of these experiments showed no change; eight gave a faster pulse rate; and eight resulted in a temporary increase in rate followed by a decrease which was generally small, and later returned to normal. The main change during the feeling of relaxation was a slowing of the pulse generally, but this slowing was in perhaps half the tests preceded by a temporary quickening in the first moments of the "letting down" feeling.

It will be noted that there were only four conditions under which a slowed pulse was obtained. We have already discussed and rejected as meaningless because complicated by release from nervous strain, the experiments with colored lights when S was subject. A second condition is in relaxation, when the change is little more than a reaction back to normal added to any effects of fatigue. The whistle in the third place caused a secondary slowing. There seems to be a tendency to

both acceleration and inhibition with these strong stimuli; and the rule is that the acceleration is stronger at first, the inhibition, a little later and this decrease in rate is generally small, and is often absent. In fact, the effect of such stimuli upon the heart rate is not nearly so marked as might be expected, not so much as that of the more lasting weaker stimuli, and is not at all in proportion to the effect on the volume. Of course the increase in rate may be due either to inhibition of the vagus nucleus of excitation of the accelerator centre.

The fourth type of decrease in heart rate, that with sensory attention, requires more notice. It is not the reaction to the feeling of strain which is so evidently present. For in the first place, this feeling was fully as strong and as pure in the multiplication experiments, and these gave a shortened pulse. Again, in all except two cases (in which there was no change) of longer effort of attention to both auditory and visual stimuli there was an increase in the rate above the normal in the second run, and in several cases this occurred before the end of the first run. And at least five records showed no slowing at first, the quickening was only delayed. These facts suggest that the real tendency of the effort of attention, the strain shall I say, is to shorten the pulse, and that this tendency is held in check at first by some other factor which tends to lengthen the beat. And at least an indication of this second factor is readily found. It is here in sensory attention, particularly in the earlier part, that one finds by far the most effective decrease in amplitude of breathing, and this generally goes with a much smaller increase in the rate of breathing than is caused by many other stimuli; it may even be decreased. The natural results of this both indirectly and directly by the lessening of the cumulative effect of the respiratory centre upon the vagus would be to lengthen the pulse. No experiments were designed to test this consequence of breathing changes directly, but a measurement as careful as possible under the conditions made upon curves taken for another purpose showed such a pulse change.

No difference was found between visual and auditory attention. There was no difference between agreeable and disagreeable conditions.

A few changes in the Traube-Hering wave in the heart rate have some significance. Agreeably exciting and agreeably depressing music, disagreeable tastes and the disagreeably exciting whistle, tended strongly to eliminate the wave, never increased it. Agreeable taste is ambiguous, twice increasing and twice decreasing it. One of these increases with agreeable taste was accompanied by large variations in breathing. Sorrow, with slowed and irregular breathing, exaggerated the Traube-Hering in the pulse. Strain in attention lessened

the wave during the stimulus; it usually returned in relaxation, and in some cases was markedly increased then, a phenomenon which may perhaps be connected with the less aerated blood.

The rate of breathing was almost always increased; in smaller degree for sensory attention than for any other stimulus. Indeed, two cases of sensory attention showed a temporary decrease in the breathing rate preceding the increase, one, gave a distinct decrease and one no change. No other condition was accompanied by a decreased rate.

Each of the original records on which the plethysmographic tracing was clear enough to show the volume changes of the Traube-Hering wave was carefully studied and the highest and lowest points of volume marked. The corresponding lines were then designated in the pulse length charts by the abbreviations T= trough and C= crest. These abbreviations were placed under the curve to which they refer. An examination of these results showed that the crest of the volume wave may fall anywhere on the rise of the pulse-length wave, more often near the crest than near the trough; that the trough of the volume wave may fall anywhere on the descent of the pulse-length wave, but still more often near the trough than near the crest. So that the fall of volume will correspond with a part, commonly the smaller part of the rise in the pulse-length curve, and with a part, still more commonly the larger part of the fall of the pulse-length curve. The rise in the volume will correspond with a part, generally the smaller part of the fall of the length curve, and a part, less generally the larger part of the rise in the length curve.

I have spoken above of a Traube-Hering wave in the breath rate. Perhaps it should not be given this name, for I cannot be certain of its relations, and, in any case, it is much obscured by more or less voluntary influences. But such a wave in the breathing is often found during sleep, and this fact naturally suggests that a similar relation may play some part here. I must, however, leave this also for a fuller treatment later.

An Introspective Report and Conclusions.

The subjects were, in general, asked to classify the mental states in terms of strain, relaxation, excitement, depression (rest), agreeableness, disagreeableness, rather than to give an account of the more intimate nature of these processes. Yet some effort was made to get at the matter more closely. If it is unsuccessful, it may at least be suggestive, and may emphasize the need of a more careful study of the introspective side.

Strain is described as composed of sensations from the muscles, the backflow from the acting muscles, particularly those

of accommodation of a sense organ. But so is excitement also. Possibly other organic sensations are more involved in what is often called a state of excitement. It is reported of a stimulus that it "kept me on edge all over," "seemed to stir every spot of the body." A condition reported as excitement seemed afterward to be "an indefinite, uncertain, muscular strain." "Felt tingling all over." It may go only so far as to "wake one up," give an increased sensation of muscular tonus.

These analyses, particularly of excitement, are made only after the original experience, or as the stimulus is ceasing. So it is reported after a whistle: "Every shiver seemed to rush in at once, then relief." Relaxation after strain was described as "the receding and more or less indefinite reverberation of the feelings during attention." It is useless to quote many of the introspections. In short, both strain and excitement are analyzable into organic, particularly muscular sensation for the most part; of course, the sensations aroused directly by the stimulus, as the noise, are also involved. When so analyzed, they lose their character as feeling, we have something else; but that is another matter. Yet there is a difference. Strain may be imperfectly analyzed and is felt to be so, as long as it is called feeling; but so far as it is analyzed, every part connects with all others. The whole state turns as a sort of system around a central controlling process. Although not to itself, yet to an onlooker it is teleological as a whole.

In excitement, there are several ends, or several may be read into it; several directions of movement of the strain of consciousness, but none clearly defined and dominant. It is not a closed system of association where every part is associated with every other in its place. It is not the rate of succession of mental processes, it is a half fusion of different lines of association that characterizes excitement. Mutual inhibition may be one means of holding a number of such chains imperfectly in consciousness. Obviously there is no sharp line of demarcation between strain and excitement; such intermediate conditions we find often with a high whistle. It is best to describe the matter this way, rather than to say we have here a mixture of the two.

Relaxation seems to be a release from either strain or excitement. We know the difference in the "letting down" feeling in the two cases, because we feel the difference in the states that are lingering. But in either case, the feeling is a returning from the character of sensation one gets from the active muscles to the kind of sensation from the lax muscle, and partakes partly of the nature of both. It is hardly an opposite of either strain or excitement in the way that disagreeableness

is the opposite of agreeableness. It originates only in a release, is a secondary instead of a co-ordinate state.

Depression, rest, name feelings that at least at first sight seem to have more varied forms. It is, I think, based upon a different kind of sensory content, that from the quiet muscle, or one easily acting. These sensations lack the peculiar quality which we call strain when it is isolated as a quality (not feeling). A different rhythm at least gives it a different quality. It comes to be associated with, to mean a condition of, little or no motion. But this is a secondary factor. The tendency to such a condition may be felt as resistance or not, according to circumstances. Thus, if I am sleepy and can go directly to sleep as I choose, the feeling is one of rest, no active oppression. But if I am attempting to work, or if a stimulus is acting that tends to excite me in any way,— in either case there is a felt oppression, a shutting down upon the activity. Looked at in this way or thought of simply as rest or quietness, in any case it is as much an opposite of strain as of excitement. We cannot have it simultaneously with either strain or excitement, except when felt as oppression, and continued strain as well as excitement gives rise to depression. Yet it is not an opposite of either in the way that disagreeableness is the opposite of agreeableness,— it is simply different. B's introspections at least, bear me out in this report.

The most important introspection bearing on the agreeable-disagreeable phases of experience was that to interrupt suddenly an agreeable stimulus is felt more as a shock than to interrupt a disagreeable. It suggests a view which we may perhaps express by saying that the stream of consciousness, always has a momentum. One status is always a condition for the becoming of the next, even though the next be like the present. There is a character of expectation, or that which makes expectation active as much in a continuous sensory process as in looking for a change. These are only two special cases. Agreeableness is then success, disagreeableness failure, but not necessarily in moving toward some other end. The process is a measure of the ability of one stage to adequately prepare for the next. Perhaps this says little more than that disagreeableness has more in common with the interruption in mental process, the fact which I have noted above, but it is so far suggestive.

I return now to the experimental results. Whether the above considerations are correct or not, I think I may speak with more confidence of the organic reactions. I find that feelings cannot be classified on the basis of vasomotor and heart rate changes. There is no reverse relation even between

the accompaniments of agreeableness and disagreeableness; much less are there three such pairs of reactions. The tridimensional theory would make strain give a lengthened pulse, relaxation a shortened pulse. In these results they give just the reverse, except as the rate with strain is modified by inhibited breathing. Agreeable, agreeably exciting and agreeably depressing states all give distinctly faster pulse and fall of volume. Neither Wundt nor Lehmann can explain this. Wundt would have the exciting and depressing phases produce no change in heart rate, and agreeableness cause a slowed pulse. Hence, in all these three cases, he should find a lengthened pulse beat; and Lehmann's theory calls for the same at least with agreeableness. Both also hold that agreeableness (and Wundt adds excitement) increase the volume,—we find the reverse. And I wish to emphasize also that the brain does not in my results decrease in volume with agreeable stimuli, and the size of the brain pulse does not decrease with disagreeableness. I need not repeat in detail the reactions summarized at the end of each section of the paper. It will be seen, that, if this work is valid, neither Wundt's nor Lehmann's theory can be allowed.

In short, all moderate nervous activity tends to constrict the peripheral vessels and to increase the volume and size of pulse in the brain. All moderate nervous activity likewise increases the heart rate. Strong stimuli cause both an exciting and inhibiting effect, which is seen especially in the heart rate. They also cause a double reaction in the brain. The most marked effects are at changing periods, particularly with an incoming stimulus. Lastly, the activity of any part, or the prominence of sensations from it tends to counteract constriction in that part.

We may explain these results in part, as follows. It is probable that all moderate nervous activity also causes constriction of the splanchnic vessels. Strong stimuli seem to have both an exciting and inhibitory effect upon them. The results in the heart rate may, of course, be due to an effect on both the vagus and exciting centres. The increase in the volume of the brain is probably in part at least due to increased blood pressure from the constriction of the periphery. It is not attention as such that causes the change. It may be simply reflex. It does not seem necessary that the stimulus reach consciousness, contrary to Lehmann's assertion. At any rate, I think this is indicated by experiments during sleep. Local control in the brain at least by constriction is indicated, but I leave this question open for the present. Perhaps the fact that the activity of any part tends to counteract constriction in it is due to the action of vaso-dilator nerves. The circulatory con-

trol depends upon physiological processes that vary roughly with what one is doing.

I append here some references bearing directly on the subjects studied, and most of which have been noted in the text.

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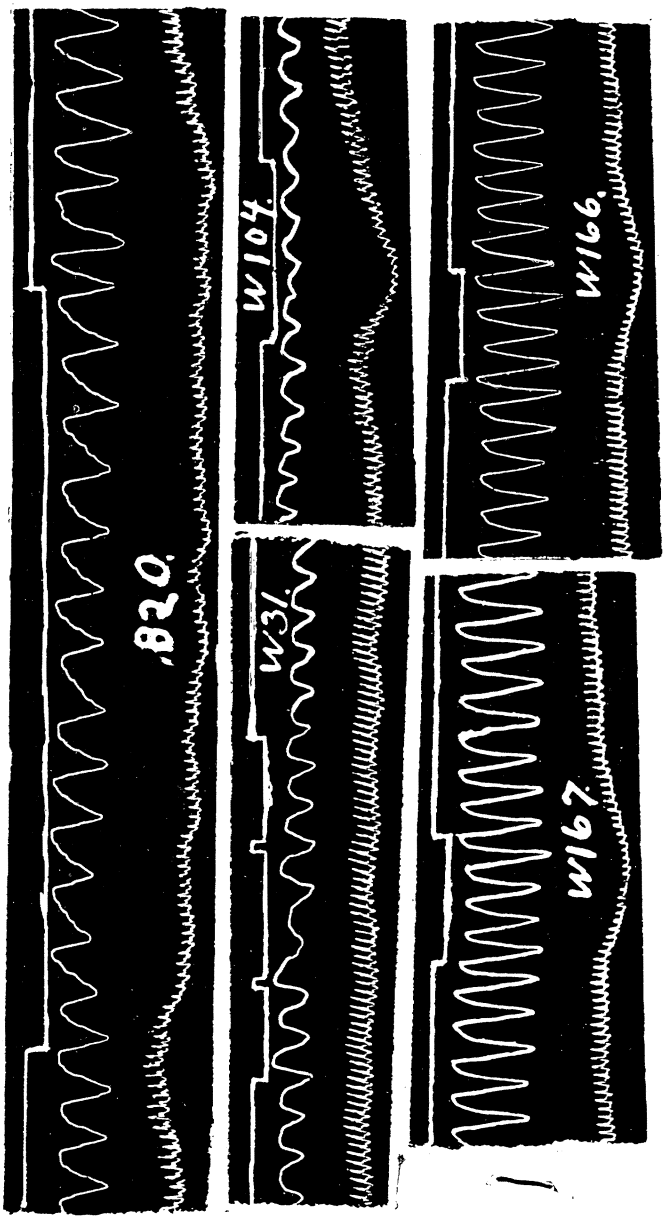


PLATE I.

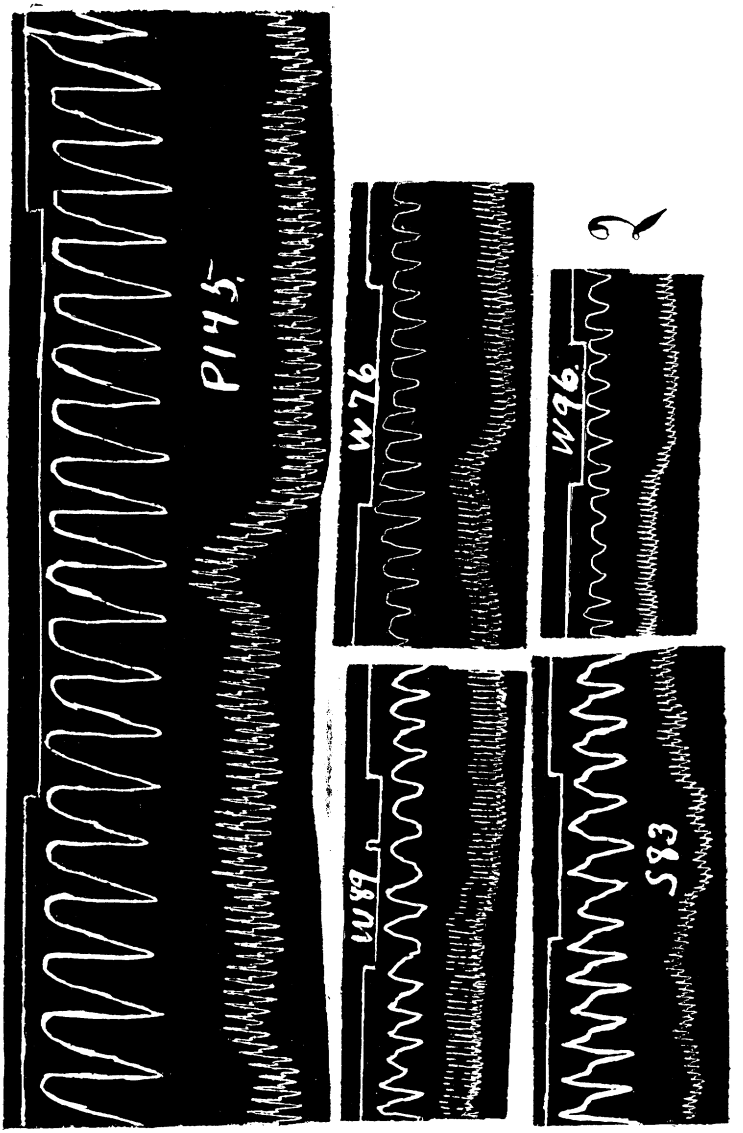
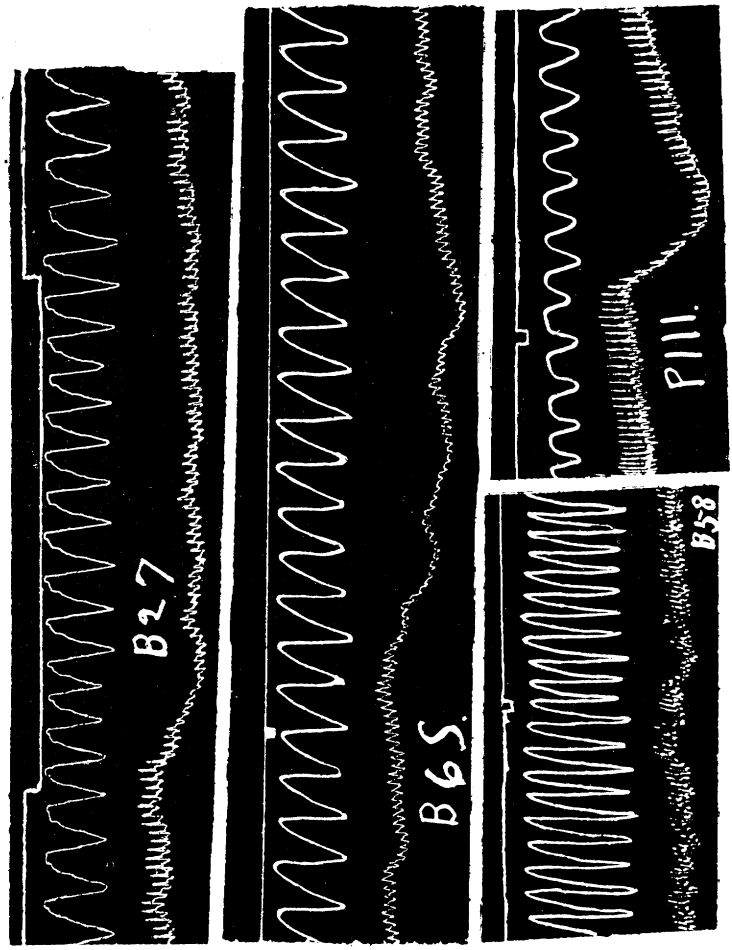


PLATE 2.



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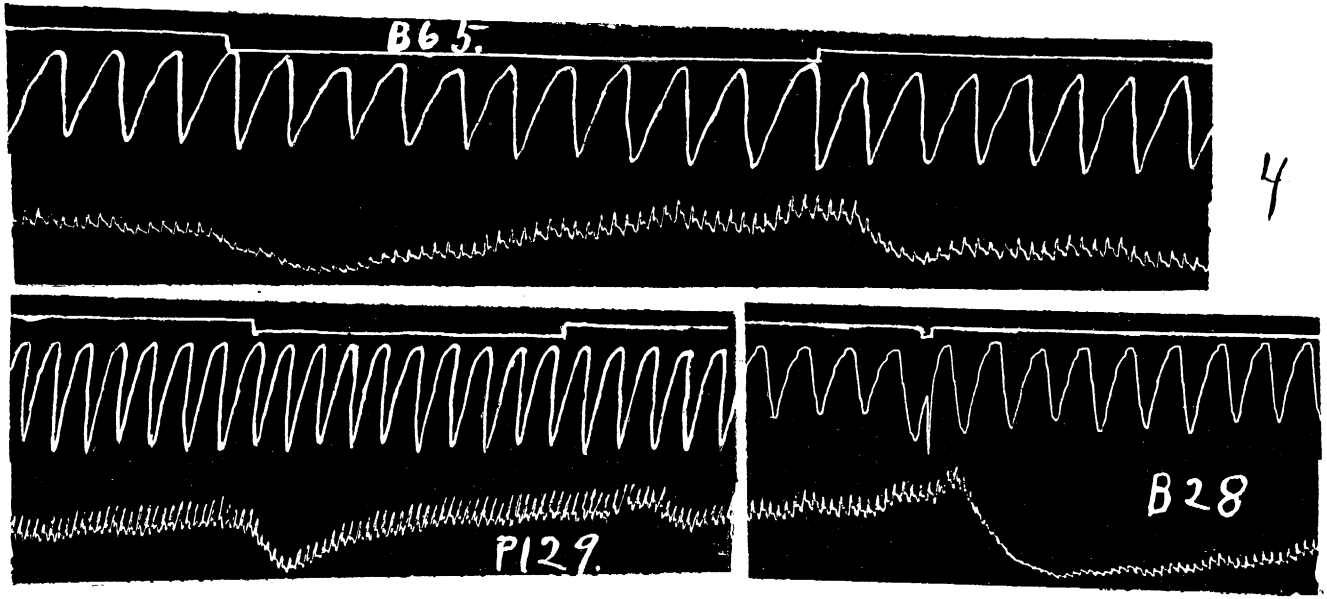

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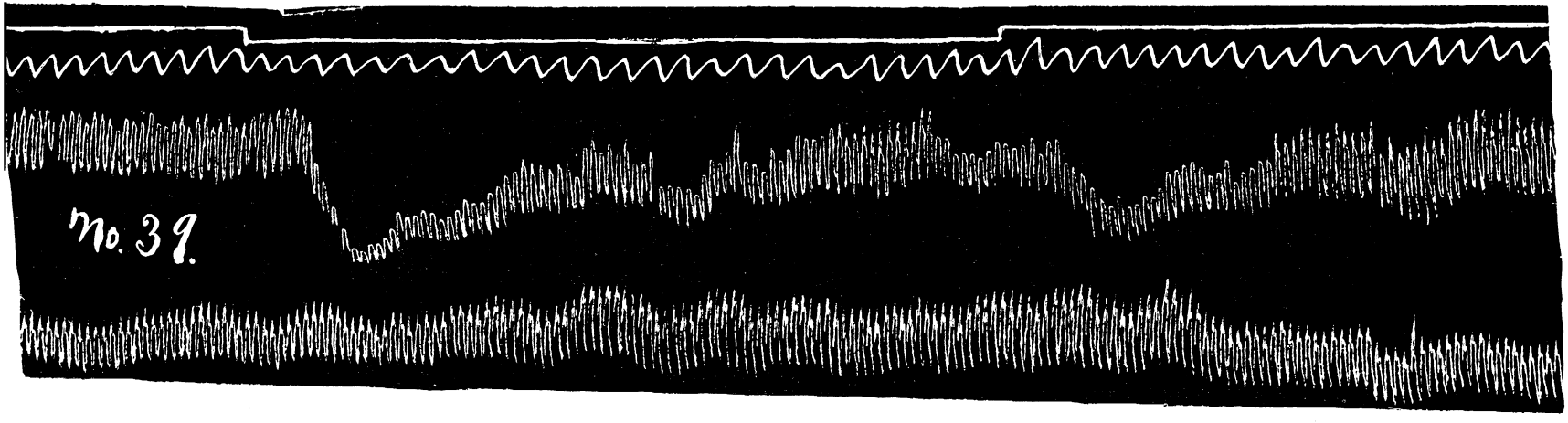

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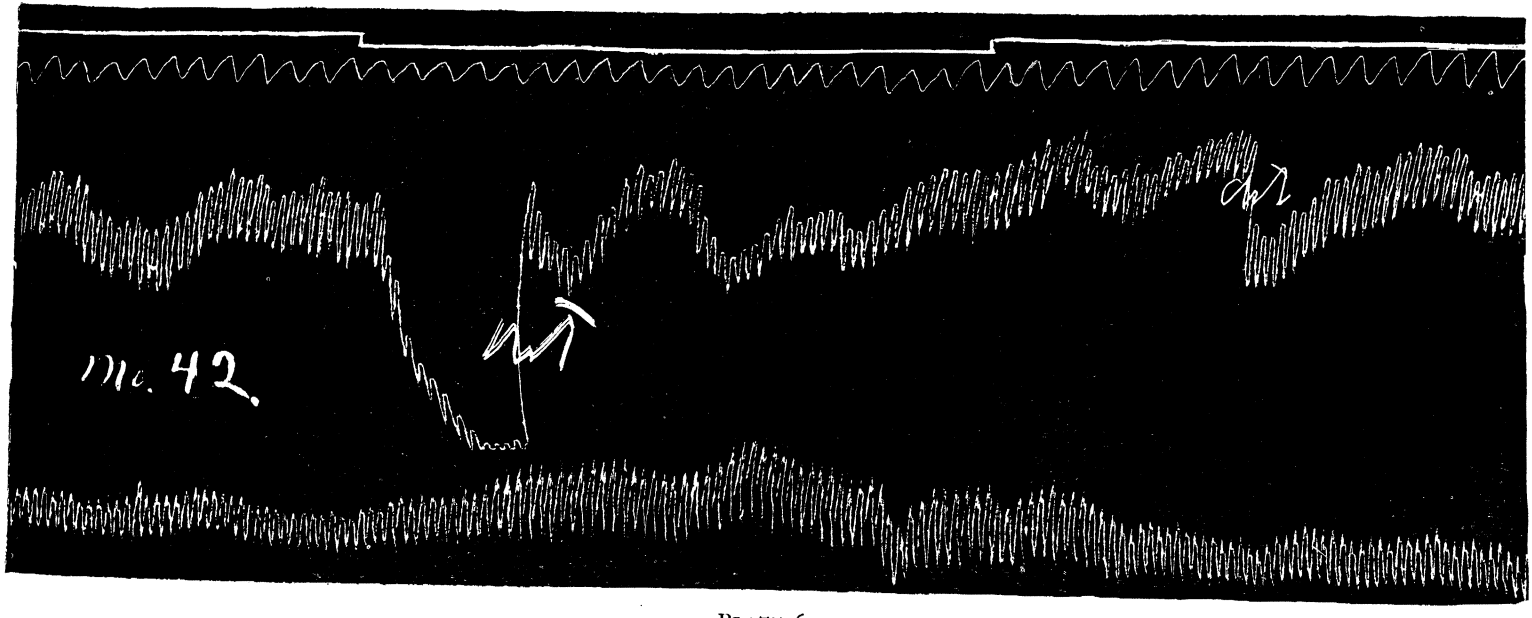

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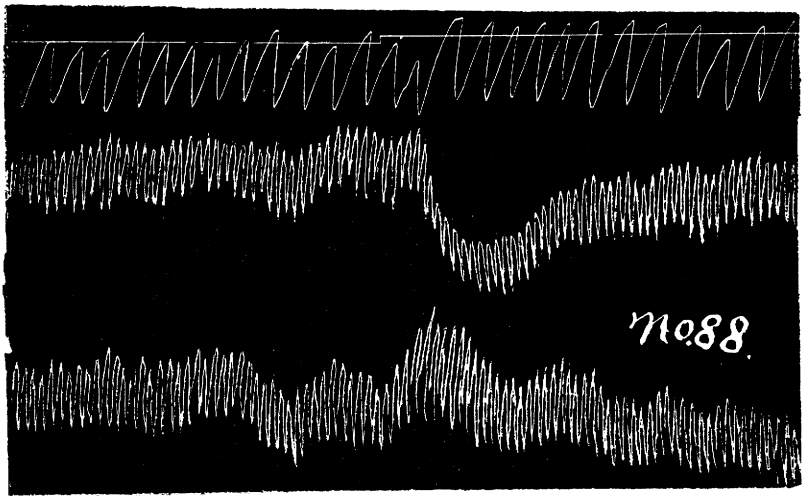

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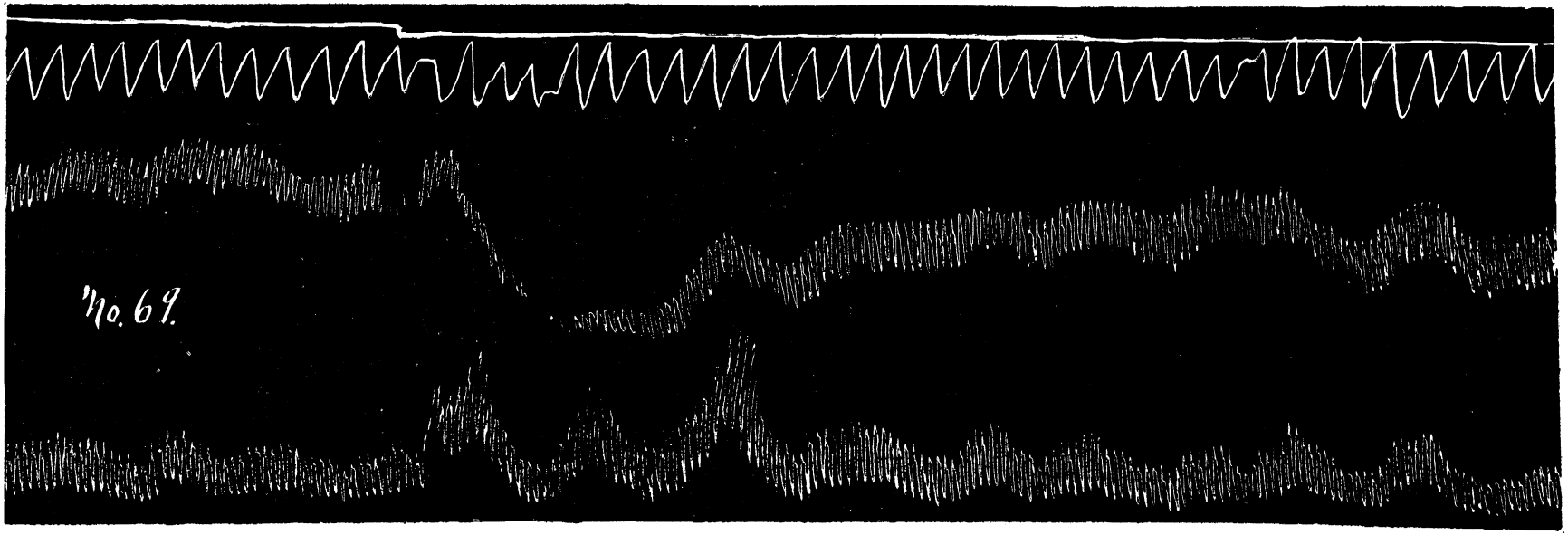

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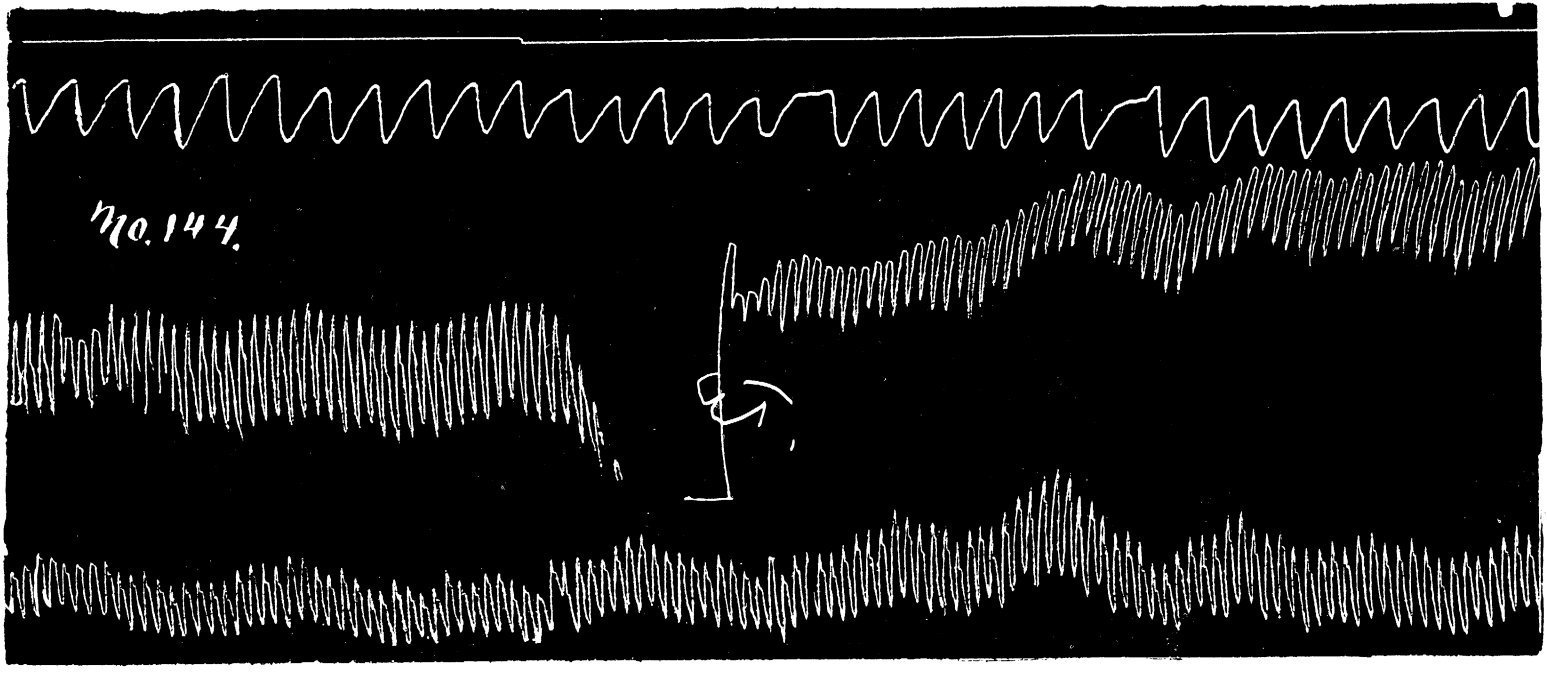

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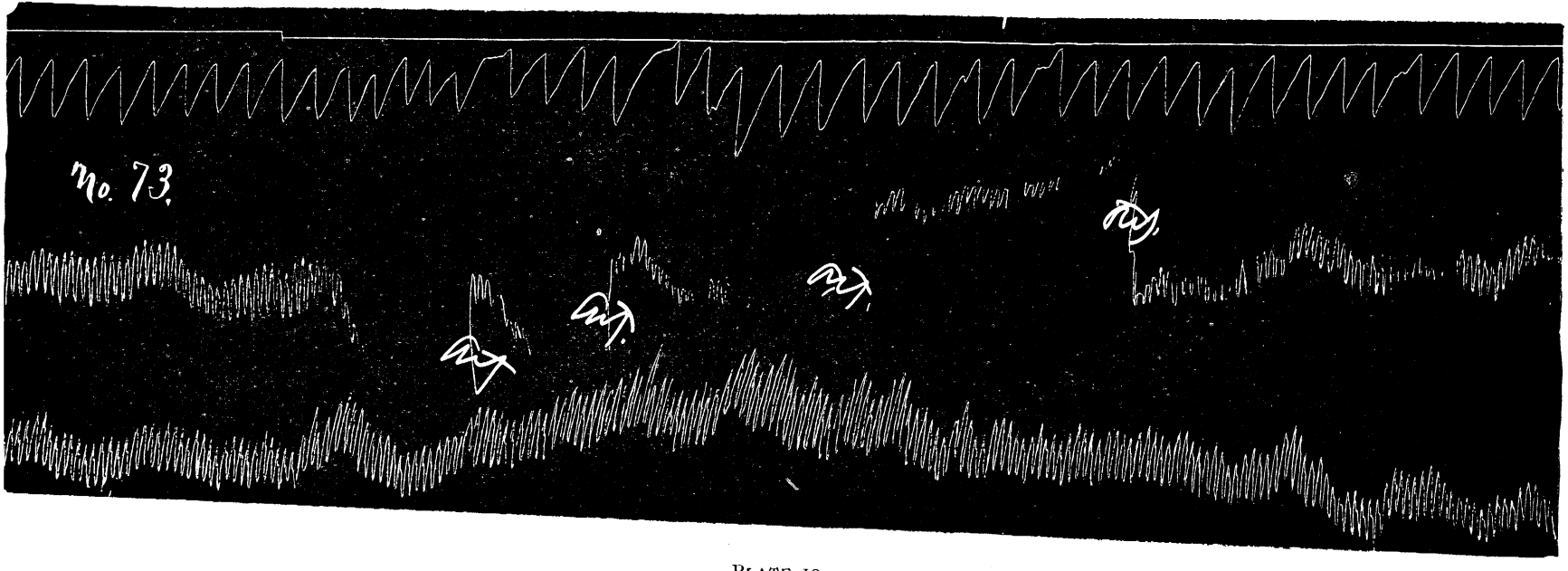

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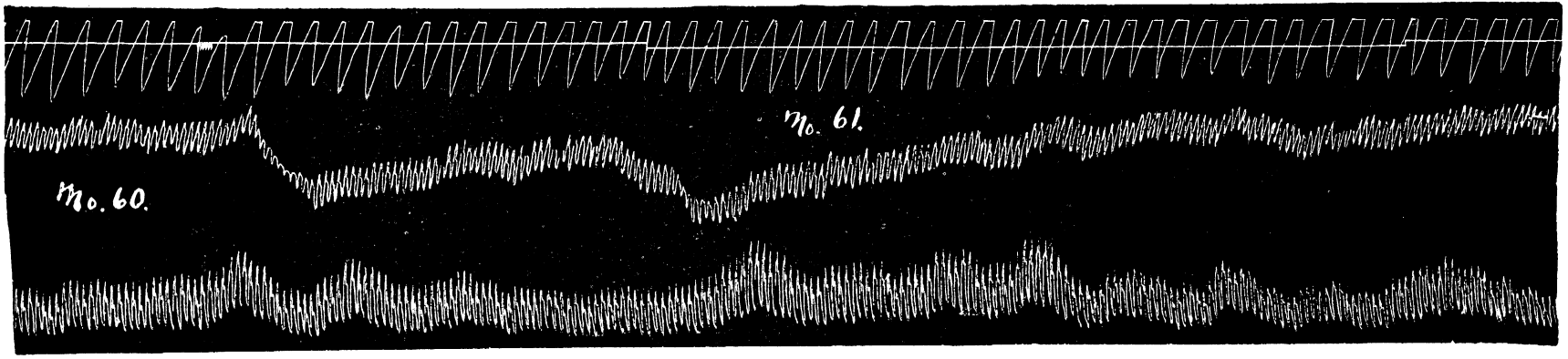

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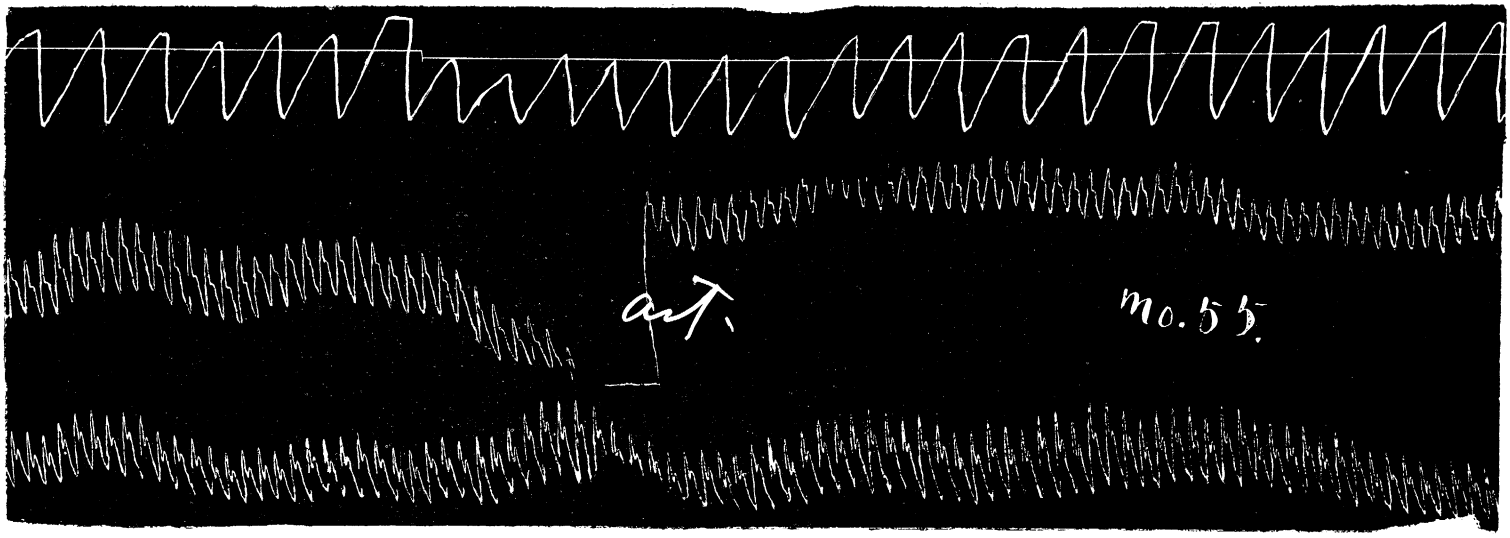

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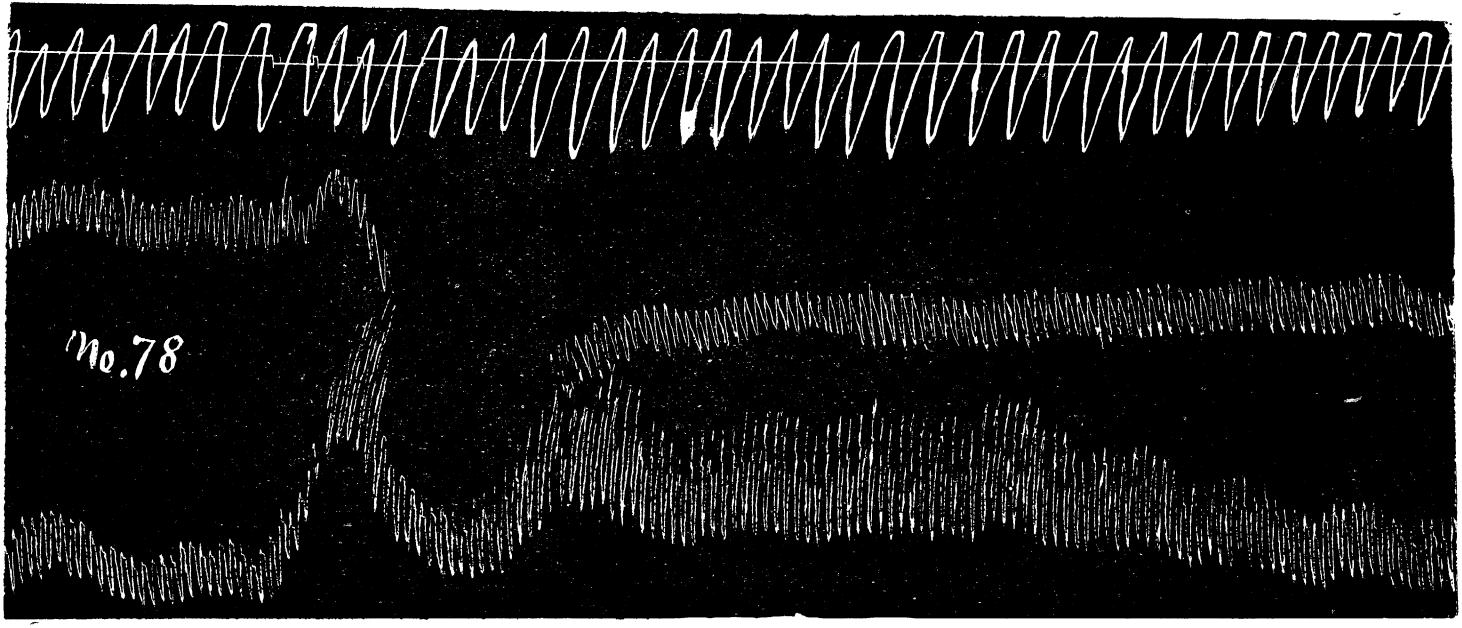

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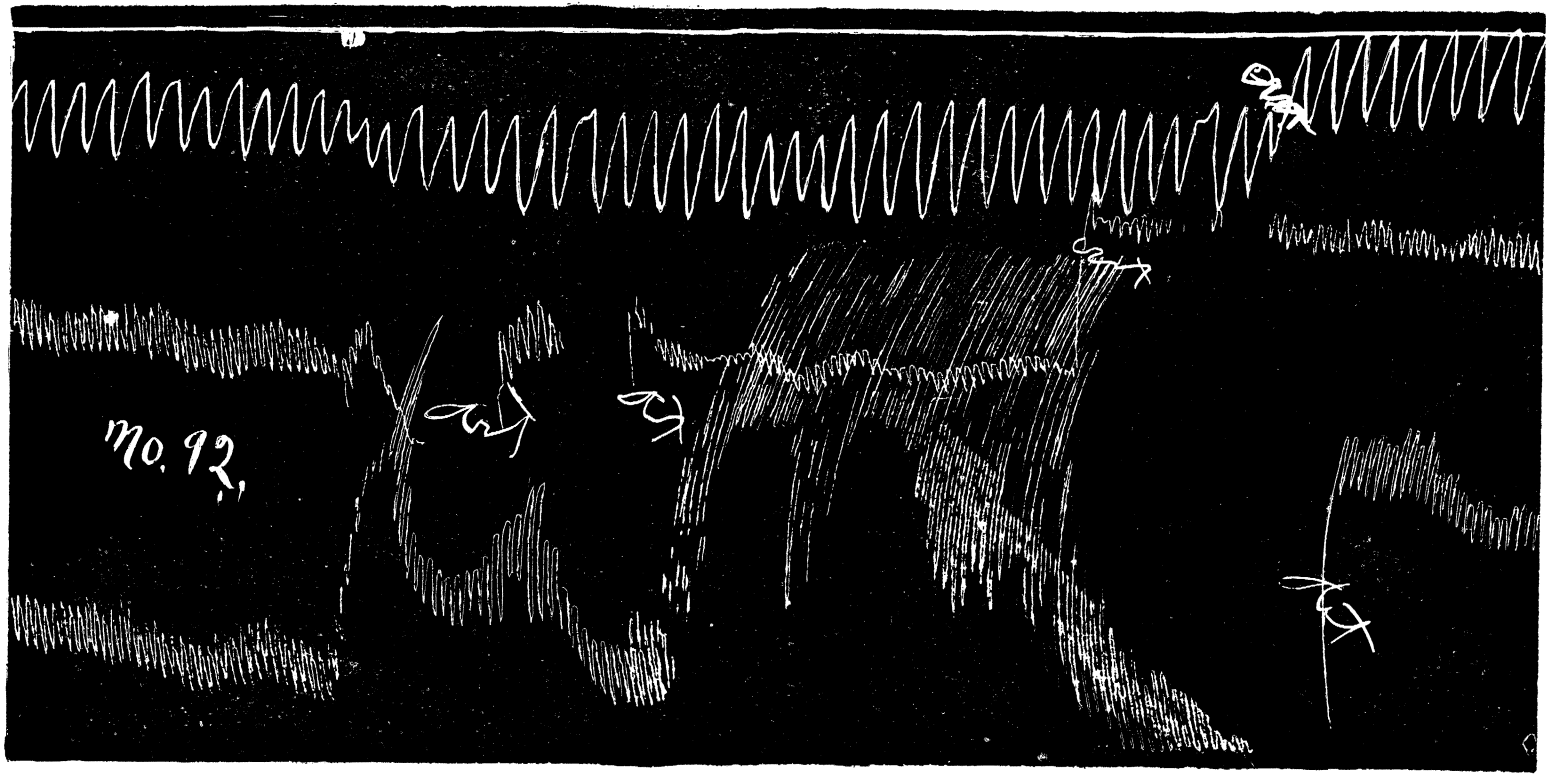

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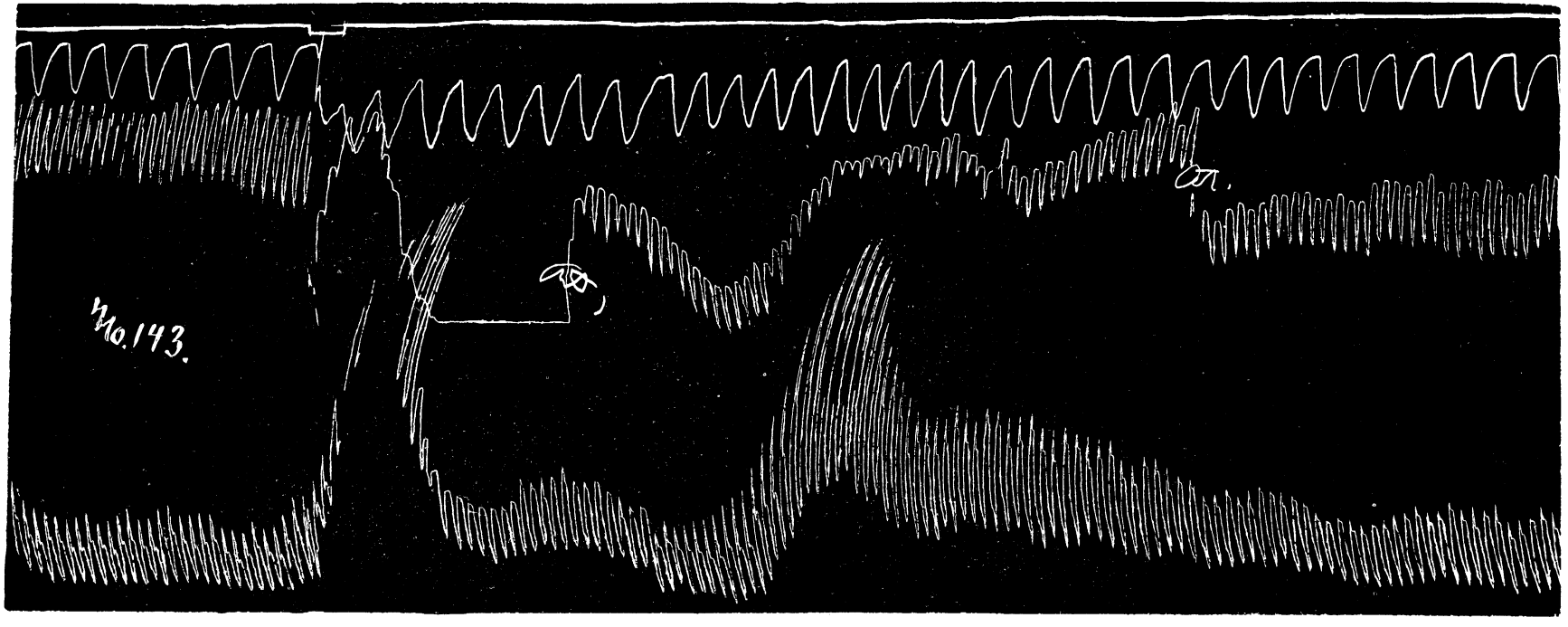

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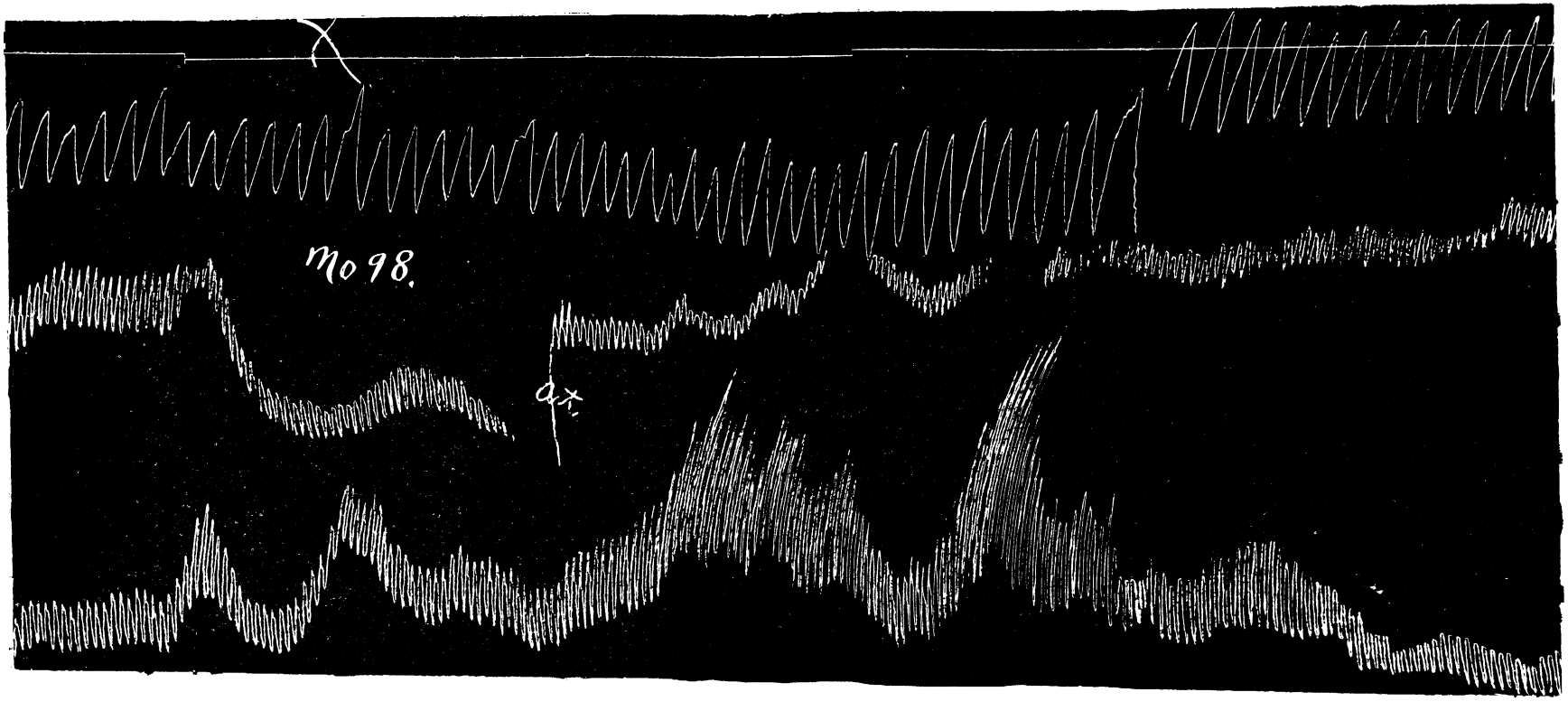

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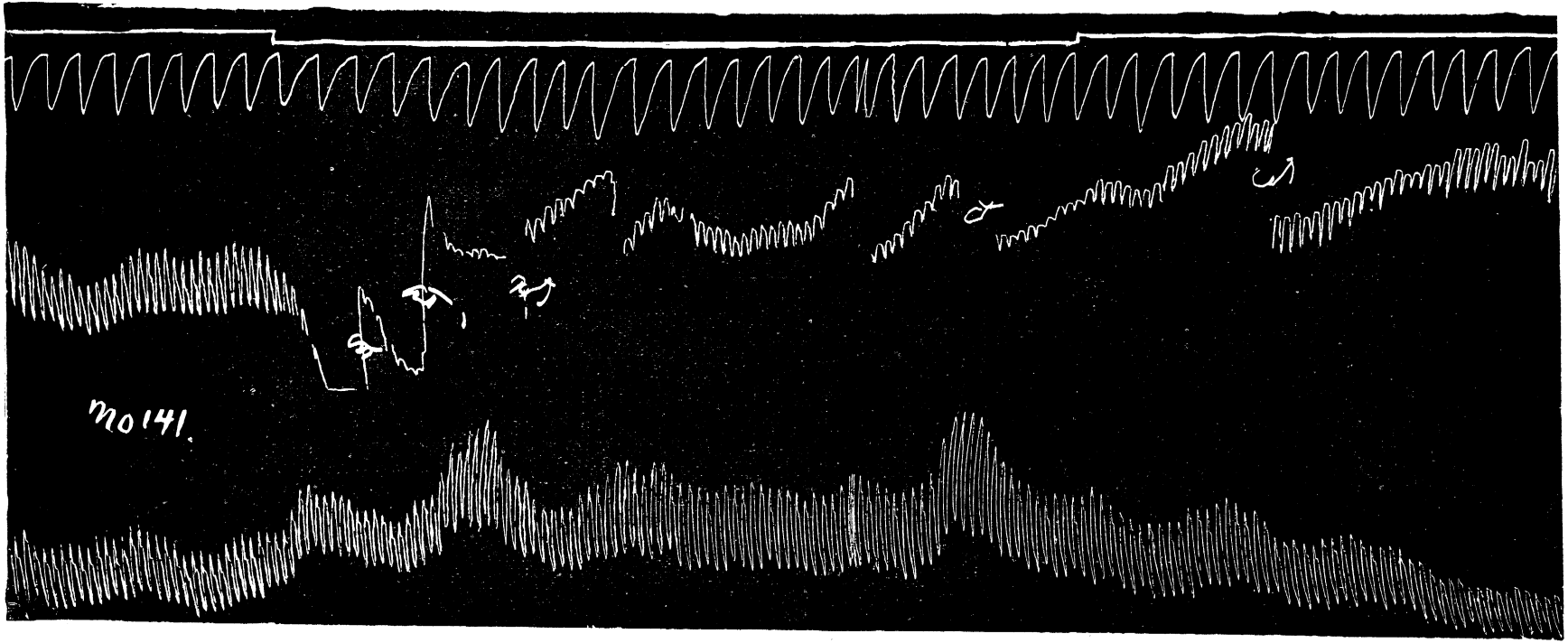

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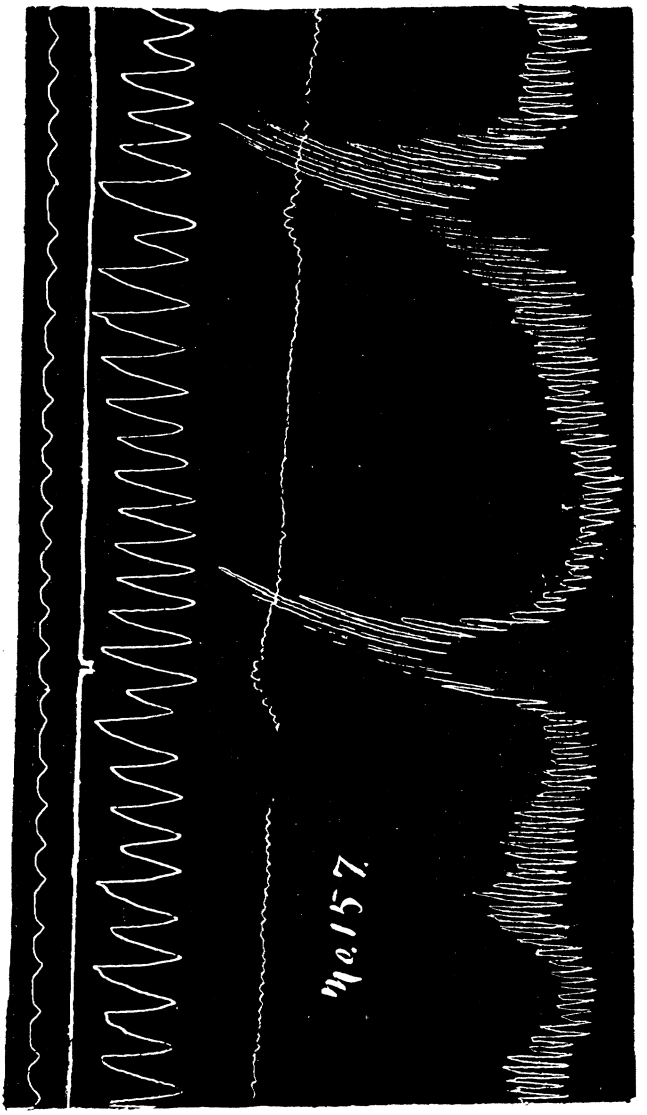

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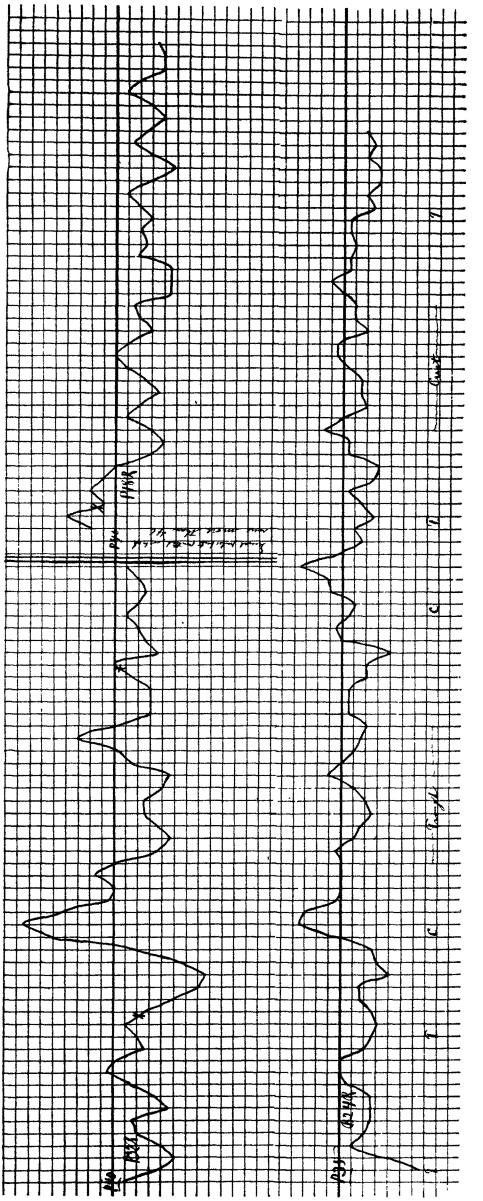

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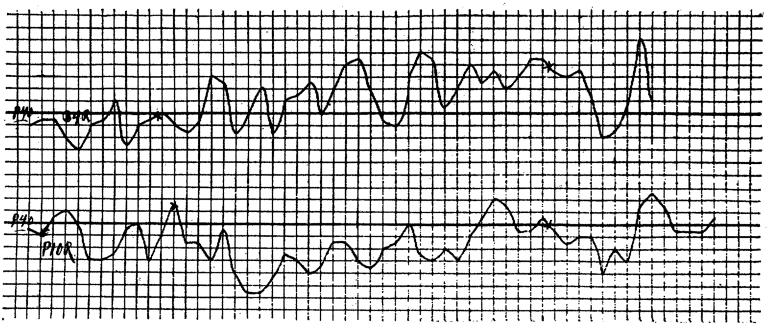

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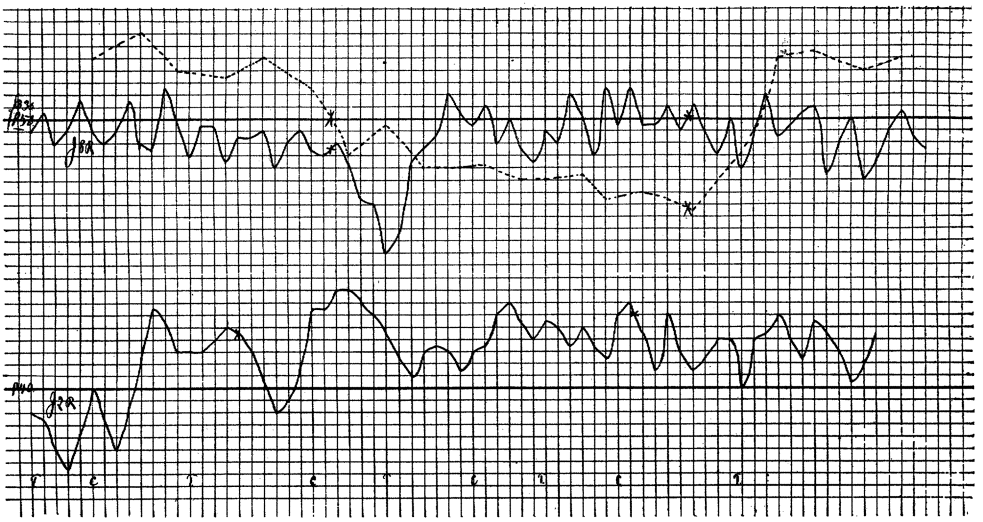
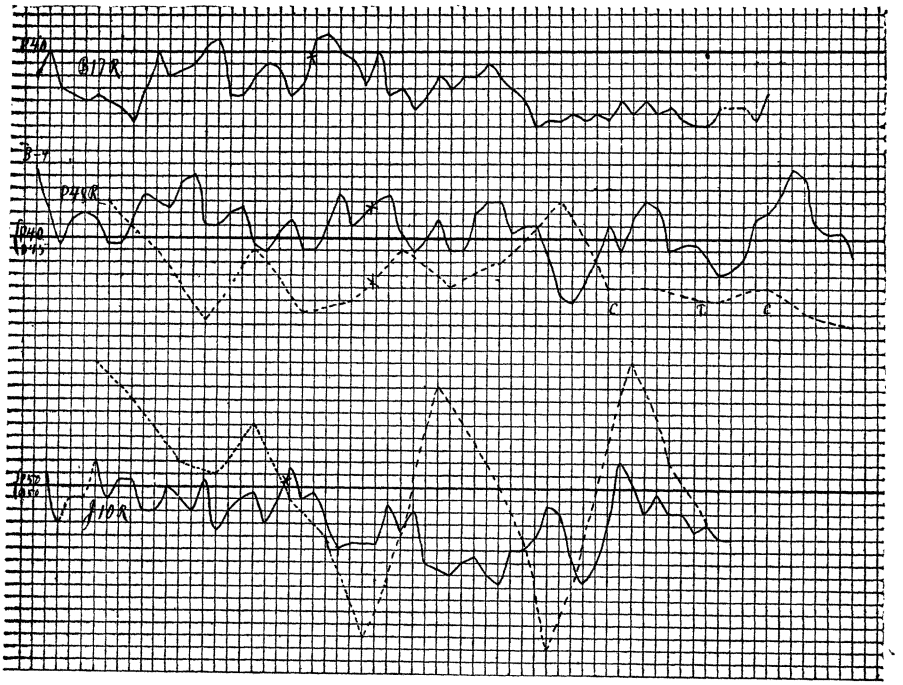


PLATE 21.

PLATE 22.



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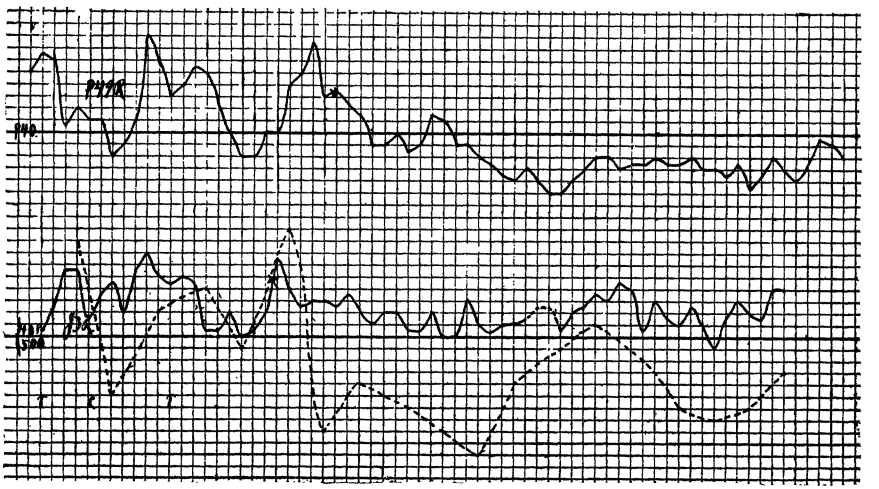

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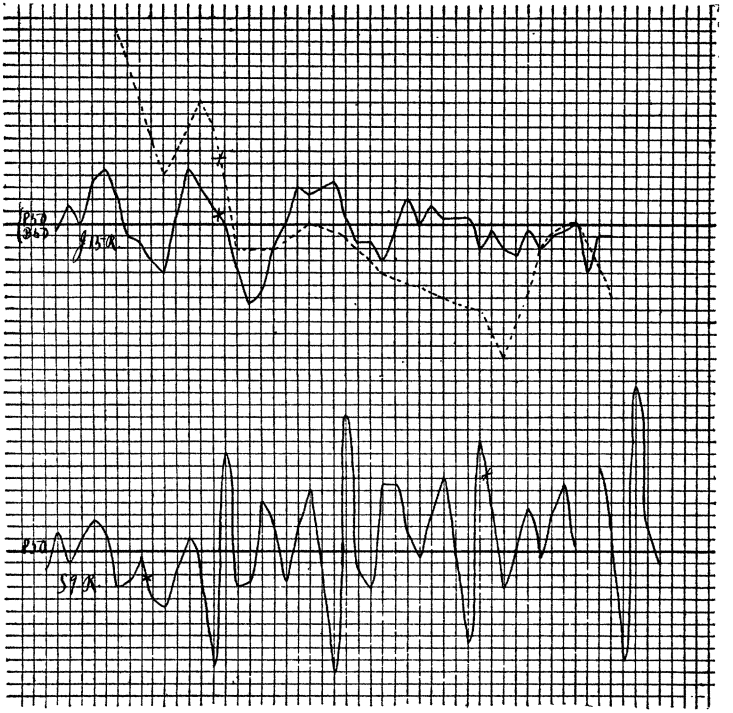

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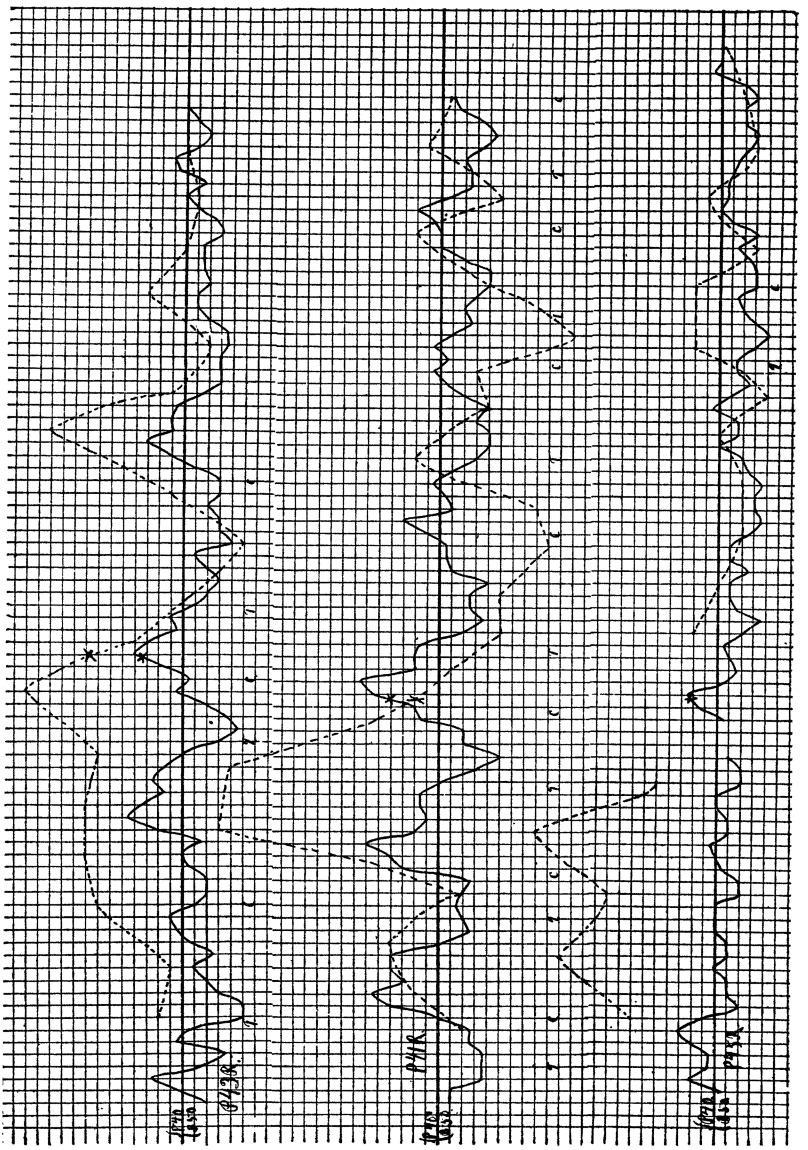

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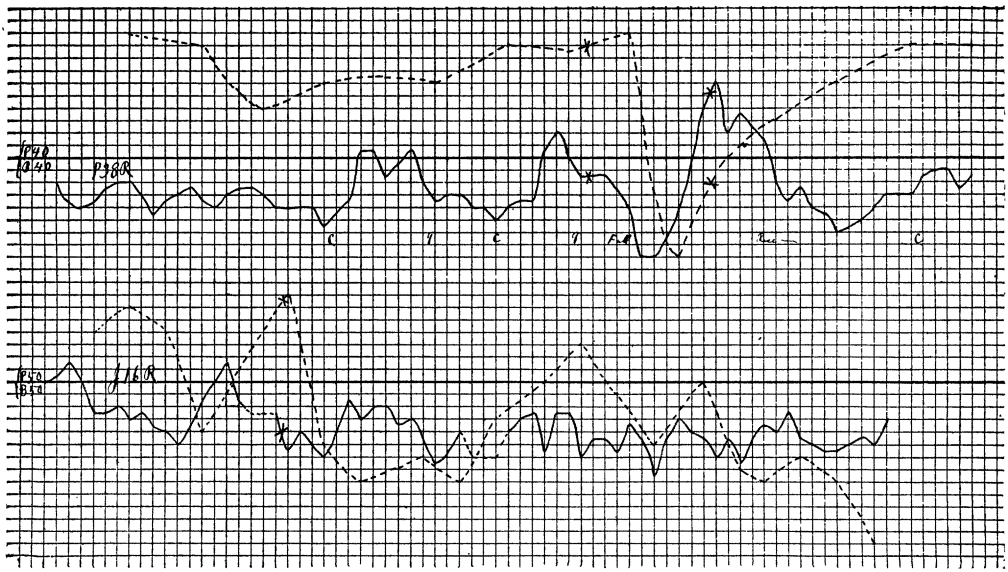

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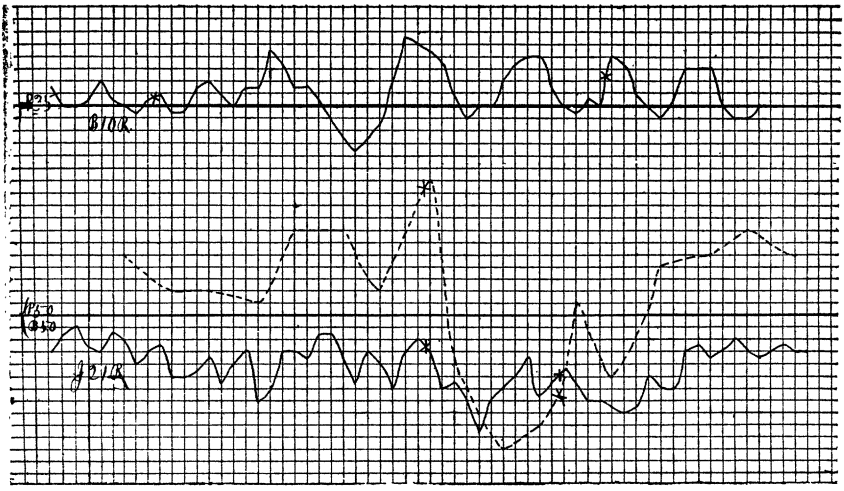

PLATE 28.